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USSR Report

METEOROLOGY AND HYDROLOGY

No. 7, July 1979

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WORLD CLIMATE CONFERENCE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 5-7

[Article by Yu. A. Izrael', Corresponding Member USSR Academy of Sciences, Chief of the Soviet Delegation to the World Climate Conference, and Professor Yu. S. Sedunov, member of the International Organizational Committee of the World Climate Conference]

[Text] The World Climate Conference, a conference of experts on the subject "Climate and Mankind," was held in Geneva during the period 12-23 February 1979. It was organized by the World Meteorological Organization with the cooperation of other UN agencies, governmental and nongovernmental organizations. Preparations for the conference were carried out by the organizing committee since 1977, during which its program was drawn up, its agenda and speakers were determined and work was done on preparation of the reports and their collation. It was decided to carry out the conference in two stages. During the first week specially selected speakers were to present 25 reports for discussion by a wide range of specialists. In the course of the second week of about a hundred selected experiments, on the basis of the presented reports and their discussion there should be preparation of a number of conference documents having the nature of recommendations.

The program for the first week of the conference included an examination of the problems involved in the present status of climate and its variability on the basis of available empirical data, study of the climates of past geological epochs, analysis of the physical mechanisms exerting an influence on climatic change, and data from physical-mathematical modeling. Provision was made for a discussion of the problems involved in the monitoring of climate, the influence of human activity on climate and a detailed analysis of the influence of climate and its variability on such aspects of human activity as the use of energy and water resources, food production, land use, sea fishing and exploitation of the coastal zone, forestry. The program provided for a discussion of the problem of climate and the health of man and the social problems associated with climatic change. Among the selected speakers were four representatives of the USSR. Academician Ye. K. Fedorov prepared a report entitled "Climatic Changes and Mankind's Strategy," Academician I. P. Gerasimov spoke on "Climates of Past Geological Epochs," Academician G. I. Marchuk dealt with "Modeling of Climatic Changes and Problems in Long-Range Weather Forecasting," while Corresponding Member USSR Academy of Sciences Yu. A. Izrael' reported on "Monitoring of Climate and the Service for Collecting Climatic Data Necessary for Determining Climatic Changes and Fluctuations. Monitoring of Data Related to Climate." [The basic content of these reports is presented in this number of the journal.]

During the first week about 350 leading scientists and specialists from more than 50 countries and representatives of international organizations participated in the conference. The Soviet delegation, consisting of 25 persons, outstanding scientists and responsible representatives of departments interested in the climate problem, exerted an active influence on the course of the conference and the work of all its sections. The conference was opened by the Honorary Chairman, the WMO General Secretary Davies, who spoke the introductory words. A welcome to the conference was presented by the Deputy General Secretary of the UN, representatives of the World Health Organization, World Environmental Program, Food and Agricultural Organization, UNESCO, International Council of Scientific Unions, and International Institute of Systems Analysis. The report by Academician Ye. K. Fedorov was presented after the introductory words by the conference chairman White.

The presentation of the reports and their discussion continued during the week.

The second week of the conference, when the number of participants was limited only to invited experts, about 120 persons, was devoted to work on documents. A group under the chairmanship of Professor Bolin (Sweden), which included a USSR representative, Academician Ye. K. Fedorov, and a representative of the Polish People's Republic, Professor Kaczmarek, prepared the text of a declaration which then was discussed at the plenary session, and four working groups prepared documents on the following directions:

1. Climatic Data and Their Use.
2. Influence of Society on Climatic Changes and Fluctuations.
3. Influence of Climatic Changes and Fluctuations on Society.
4. Investigation of Climatic Changes and Fluctuations.

These documents were approved by the working groups and will be used extensively as scientific recommendations in preparing the World Climate Program.

At the concluding plenary session approval was given for the final form of the text of the Declaration of the World Climate Conference. [The text of the World Climate Conference Declaration is given in this journal.] This declaration, addressed to the countries of the world, includes important principles relating to the present state of climate, its future changes, and contains conclusions and recommendations in which there is expression of universal support of the need for an unpostponable implementation of the World Climate Program and its principal components for study of the main mechanisms of climatic change, improvement in the collection of climatic data, use of climatic data for practical purposes, study of the influence of climatic changes and fluctuations on human activity. It is important to note that the declaration emphasizes the importance of close international cooperation and the necessity for peace on earth.

The conference also examined the problem of carrying out a conference, at the minister level, on problems relating to climatic change and it was concluded that its organization in the immediate future is infeasible.

The World Climate Conference, which transpired extremely successfully, is an exceptionally important event and the results of its work will essentially determine future measures for coordinating the efforts of countries and international organizations in the study of a highly important problem of modern times -- climatic change and its predictability.

It was decided to publish, for widespread dissemination, the materials from the conference: reports, conclusions based on discussions, reports of the working groups, conference declaration and also the welcomes and complete list of the participants.

The conference materials will have exceptionally great importance for completing preparation of the World Climate Program, and its recommendations were taken into account in discussing the program for the Eighth WMO Congress. The conference materials, the declaration, the conclusions drawn from discussion of the reports, and the reports of the working groups were presented to the congress. In particular, the conference specially expressed itself with respect to the section of the World Climate Program directed to study of the influence of climate on human activity. The plan of action, directed to ensuring implementation of this part of the program, generated serious comments and it was proposed that it be reworked substantially, taking into account the results of work by the working groups.

It seems that the conference results will be extremely useful in the final reworking of the Soviet Complex Program for Investigations of the Earth's Climate. The Soviet Complex Program for Investigations of the Earth's Climate should serve as a basis for the participation of Soviet scientists in the World Climate Program and therefore it is important that its structure should correspond to our national interests and capabilities, that it be organically intertwined with the principal directions in international activity and cooperation in study of the earth's climate.

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DECLARATION OF THE WORLD CLIMATE CONFERENCE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 8-11

[Unsigned document, translated from English into Russian]

[Text] The World Climate Conference, a conference of experts on the problem "Climate and Mankind," held in Geneva during the period 12-23 February 1979, was organized by the World Meteorological Organization with the cooperation of other international agencies.

Specialists in many fields of science, gathering at the conference, expressed their opinions with respect to climatic fluctuations and changes and the consequences which this can have for the entire world. On the basis of their ideas they adopted the following.

Appeal to Countries

Taking into account the ever-increasing influence of climate on human society and many branches of human activity, the conference feels that at the present time for the countries of the earth the following is urgently necessary:
a) full use of existing knowledge of climate;
b) the undertaking of measures for considerably improving this knowledge;
c) foreseeing of potential anthropogenic changes of climate which may be unfavorable for mankind and the prevention of these changes.

Problem

Global climate has changed slowly over the course of the last millenia, centuries and decades and will change in the future. Mankind is taking advantage of the favorable climatic conditions, but it is also subject to the influence of climatic changes and fluctuations and manifestations of extremal phenomena, such as droughts and floods. Food, water, energy, housing and health, all these aspects of man's life are essentially dependent on climate. The recently observed poor harvests of grain crops and the serious reduction in the catch of some species of fish demonstrate this dependence. Even ordinary fluctuations and small changes in climate exert a substantial influence on human activity.

All countries are subject to climatic fluctuations, particularly the developing countries, and especially those which are located in arid and semiarid regions or in regions with heavy precipitation. The influence of unfavorable climatic factors can be reduced and by means of use of available knowledge of climate it is possible to gain advantages.

The climates of world countries are interrelated. For this reason and due to the increasing demands on resources for an increasing world population, which is striving for better living conditions, it is urgently necessary to formulate a general global strategy directed to the best understanding and most rational use of climate.

Man is presently involuntarily changing climate on a local scale, and to a limited degree, on a regional scale. There is a serious concern that the continuing expansion of human activity on the earth can lead to considerable regional and even global climatic changes. This possibility dictates additional urgency in organizing global cooperation in the study of possible climatic change on our planet in the future, for taking this new information into account in planning the future development of human society.

Climate and the Future

Climate will also continue to fluctuate and change as a result of natural causes. The observed tendencies to a slow cooling in some parts of the northern hemisphere during the last few decades are similar to the tendencies of natural origin observed in the past and thus it remains unknown whether this will continue or not.

Nevertheless, we can say with some assurance that the combustion of fossil fuel, the cutting of forests and changes in land use have increased the quantity of carbon dioxide in the atmosphere during the last century by approximately 15%, and at the present time this quantity is increasing by approximately 0.4% annually. This increase will probably continue in the future. Carbon dioxide plays a very important role in forming the temperature of the earth's atmosphere, and evidently the increasing quantity of carbon dioxide in the atmosphere can lead to a gradual warming of the lower part of the atmosphere, especially in the high latitudes. Such a change will probably exert an influence on the distribution of temperature, the quantity of precipitation and other meteorological parameters -- but all the consequences of this are not adequately clear.

It is possible that some phenomena of regional and global scales will be detected even before the end of this century and they will become significant before the middle of the next century. This time scale is approximately equal to the period of time necessary for reorienting, in case of necessity, the work of many branches of world economy, including agriculture and energy production. Since climatic changes may be favorable in some parts of the world and unfavorable in others, considerable social and technological reorganization may be necessary.

The increasing use of energy and the release of heat in this process have already led to local climatic changes. In the future such heat flows from densely populated regions and regions with well-developed industry may possibly exert some influence on climate on a large scale. Other types of human activity, such as agriculture, cattle grazing, increasing use of nitrogen fertilizers and the ejection of freons into the atmosphere can have climatic consequences and therefore they require attentive study. It is also necessary to make a systematic study of other possible effects on climate associated with the principal types of human activity.

Some forms of waging war can exert an influence on local climate. A world thermonuclear conflict, in addition to its catastrophic consequences for mankind, would inflict a considerable devastation of the environment, and possibly would lead to large-scale climatic changes.

It is postulated that in the future man will be capable of intentionally bringing about limited changes in climate on a large scale. It would be irresponsible to discuss such effects until we have the necessary understanding of the mechanisms controlling climate, which is necessary for predicting the consequences of climatic changes and fluctuations. Moreover, prior to initiating the implementation of such projects it is necessary to attain agreement on an international scale.

Conclusions and Recommendations

The World Climate Program, proposed by the World Meteorological Organization, merits the strongest support from all countries.

Its principal goals are:
-- Investigation of climatic mechanisms for determining the relative role of natural and anthropogenic influences. This will require the further development of mathematical models, which are a means for modeling and evaluating the predictability of a climatic system. They will also be used for a study of the sensitivity of climate to possible natural and anthropogenic effects, such as the release of carbon dioxide, and for evaluating the reaction of climate.
-- Improvement in the collection and availability of climatic data. The success of the climate program is dependent on the availability of a great volume of meteorological, hydrological, oceanographic and other necessary geophysical data. In addition, the study of the influence of climate on human activity and the practical use by different countries of a knowledge of climate will require detailed information on their national resources and socioeconomic structures.
-- Use of climatic knowledge in planning, development and control. This activity must include programs for rendering assistance to national meteorological and hydrological services in improving information supplied to users on the potential advantages which can be obtained by the use of climatic information and also in improving the presentation and dissemination of this information. There must also be programs for assistance in preparing national

personnel in the field of applied climatology. Programs are needed for the development of a new methodology for the use of climatic data in the food, water resources, energy and health sectors.
-- Study of the influences of climatic changes and fluctuations on human activity and the application of the results of such investigations for their best use by governments and peoples. This will require an improvement in our understanding of the interrelationships between climate and human society, including:
I. the possible range of society's adaptation to climatic fluctuations and changes;
II. those characteristics of human society in different stages of development and in different environments, which will make society especially vulnerable or stable relative to climatic fluctuations and changes;
III. means by use of which human society can protect itself against the unfavorable consequences of climatic fluctuations and changes and make use of the possibilities following from these fluctuations and changes.
Thus, the general objectives of the program are to ensure foreseeing possible changes in climate in the future and assist countries in employing climatic data and knowledge in the planning and control of all aspects of human activity. This will require interdisciplinary efforts of an unprecedented scale at the national and international levels.

Implementation of the World Climate Program includes a broad range of activity and will require direction and coordination among international agencies and close cooperation among countries.

It is fully recognized that international cooperation, which is a prerequisite for any world climate program, can be implemented only under conditions of peace.

There is an immediate need for countries to use existing knowledge concerning climate and climatic fluctuations in the planning of social and economic development.

In some parts of the world there is already an adequate quantity of information for rendering different types of applied climatic servicing. However, this is only the beginning; data and qualified experience in general are completely lacking for the developing countries. Programs must be drawn up for rendering them assistance for the purpose of full participation in the World Climate Program by means of training of personnel and imparting the corresponding methodology.

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The possibility of mankind existing for a long period is dependent on a harmony between society and the environment. Climate is only one element in our environment which must be reasonably used. All elements of the environment interact both locally and at a distance. The deterioration of the environment in any national or geographic region must be a reason for concern by society because this can exert an influence on climate everywhere.

The countries of the world must act together in order to maintain soil fertility, to avoid the incorrect use of world water resources, reserves of forests and pasture lands, to stop lands from becoming deserts and to decrease contamination of the atmosphere and ocean. These actions on the part of different countries will require great resolution and corresponding material resources, and they will make sense only if peace prevails on earth.

UDC 551.(583:509.6)

CLIMATIC CHANGES AND MANKIND'S STRATEGY

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 12-24

[Article by Academician Ye. K. Fedorov, Institute of Applied Geophysics, submitted for publication 13 March 1979]

Abstract: The author examines the possible natural and anthropogenic changes in climate. It is asserted that such changes of a local, regional and global character can become appreciable and possibly irreversible within the next few decades. In this connection there is a discussion of the strategy of elements of regional and global scales directed to the prevention of negative consequences of climatic changes: prediction of climatic change, evaluation of the consequences of climatic changes and formulation of appropriate recommendations. The conclusion is drawn that for the development and implementation of such a strategy it is necessary to have peace, disarmament and international cooperation. [This is the basic content of a report at the World Conference on Climate (Geneva, 12-23 February 1979).]]

[Text] Introduction. Recently specialists and a wide part of society have become increasingly concerned by possible irreversible changes in the environment, especially climatic changes. Is this a sound concern in the present era when man is acquiring ever-greater nondependence on environmental conditions and on climatic peculiarities as a result of scientific and technical progress?

In actuality, construction has lost the seasonality which earlier was characteristic for it. Melioration makes it possible to develop agriculture in the deserts. The techniques of communal management make it possible to construct large cities ensuring comfortable living conditions in the Arctic, etc.

However, by virtue of the singular dialectics of development of events the organization and assurance of activity, the assurance of the necessary living conditions, require a considerably more precise allowance for climate, like other environmental peculiarities, in order to do everything necessary in the most desirable way.

The scales of human actions -- the dimensions of structures, the transformed fraction of the earth's surface, the quantity of minerals extracted from the earth, the total of produced and consumed energy, changes in the composition of the atmosphere and hydrosphere as a result of production wastes, have increased to such a degree that they have become comparable with the corresponding elements of natural phenomena and their fluctuations. Now we cannot regard the medium surrounding us on the planet to be unlimited or its elements to be inexhaustible.

Many of our activities -- construction, melioration, etc. -- are planned for over a long period. In this connection erroneous estimates of the present and future states of both the natural and transformed environment (mineral resources, mean and extremal river runoffs, precipitation quantities, sea level, etc.) are leading to ever-increasing losses. Excessive safety factors, dimensions and power all involve unjustifiable expenditures; inadequate safety factors, dimensions and power all create a threat of destruction. In this respect climate plays a special role because virtually all branches of the economy are developing taking its peculiarities into account, and on the other hand, almost all forms of human activity are exerting an influence on it. Therefore, the problem of natural and anthropogenic changes in climate is of considerable interest. Here we will briefly examine the natural and anthropogenic changes in climate, the effect of climatic changes on the economy, the possibility of purposeful transformation of climate and human strategy, that is, the system of long-term measures which must be provided for in order to avoid possible negative effects from climatic changes.

Before proceeding to an examination of climatic phenomena, we should define more clearly what we mean by this term. Climate, from our point of view, is one of the consequences, and at the same time, one of the characteristics of the complex totality of processes operative in the atmosphere, in the ocean and at the land surface. As a result of nonuniform heating of the earth's surface by the sun a constant circulation of the atmosphere is maintained. Its initially very simple model (rising of the heated air in the equatorial zone, flow toward the polar regions, subsidence there and return flow toward the equator) is complicated as a result of the effect of the earth's rotation, special subsystems of circulation between the oceans and the continents, barriers created by major mountain ranges, etc. Nevertheless, the principal features of this model, generalized over considerable periods of time (several years, several decades), retains some constancy.

This relative stability corresponds to the conservation of definite characteristics of the state of the atmosphere and water bodies -- different in different regions of the earth, for example, mean and extremal temperatures, quantity of precipitation, river runoff for different seasons of the year, etc. The totality of these relatively stable characteristics of the state of the atmosphere, in our opinion, is what the term "climate" means. Earlier it was assumed that the climate of any region of the earth is known more precisely the longer the period of time which is taken for the generalization of meteorological data. However, since it became known that climate changes this conclusion has lost its importance. At present there is no unanimous opinion among researchers as to what period of time should be selected for characterizing climate. Most frequently, and in our opinion this is correct, a period of 10-30 years is selected, although at the conference other points of view have also been expressed.

Natural Climatic Changes

The results of geological, archeological and historical investigations indicate radical climatic changes occurring during the course of the history of our planet. It is difficult to judge the climate of any region of the earth in the very distant past because the positioning of this region relative to the earth's axis of rotation can change both as a result of movement of the continents and in connection with the possible change in the direction of the axis of rotation itself; in other words, it cannot be assumed that any specific zone of the planet over the course of all geological periods had the very same latitudinal position (or longitudinal position) as at the present time. However, there is no basis for assuming that over the course of the last several hundreds of millions of years the climate was uniform over the entire surface of the earth and did not differ substantially in different latitude zones, as at the present time. The temperature in the equatorial region was close to what it is today, but in the polar regions -- much higher. The oceans, if they existed in the polar regions, were free of ice; in addition, there were no continental glaciations.

A gradual cooling of the polar regions began several tens of millions of years ago and about a million years ago the temperature in the Arctic decreased sharply. Glaciations began to follow, one after the other; during this period the glaciers at times were propagated to the temperate latitudes and at times retreated.

The last glaciation in the northern hemisphere ended, as is well known, about 10,000 years ago.

Less significant climatic changes were also observed in the relatively recent past. For example, it is known that about a thousand years ago the temperature in the north polar region was higher than at the present time and the ice boundary in the ocean was situated to the north of its present position. This, in particular, facilitated navigation from Europe to the shores of Greenland, where at that time colonies were established which persisted for several hundred years. Then the next cooling and a considerable southward advance of the edge of floating polar ice interrupted communication with them, caused an increase and broadening of the Greenland ice cover, which together led to the death of the colony. This cooling was observed in Europe and it is frequently called a "small glacial period." Climatic changes were also noted during the course of the last 100-200 years. The temperature variations were more significant in the high latitudes. An example of this was the well-known warming of the Arctic in the 1930's, replaced by some cooling in the 1940's and 1950's.

Climatic variations are not manifested in temperature alone. There are also changes in the quantity of precipitation. The changes in the quantity of precipitation, especially in winter, falling in the northern part of the European USSR, are reflected, for example, in variations in the level of the Caspian Sea. It is known that in the course of the last four or five centuries its level has repeatedly risen and fallen by about 20 m. At the present time the level of the Caspian Sea is systematically falling, but this is caused by anthropogenic as well as by natural factors. Climatic changes reflect changes in general circulation of the earth's atmosphere and without doubt, in general circulation of ocean waters.

There are a number of hypotheses which attempt to explain climatic changes, but for the time being there is no physically validated theory which could give an exhaustive explanation of this phenomenon. From our point of view it is feasible to separate attempts at explaining climatic changes transpiring over the course of hundreds and tens of millions of years and those changes which have been observed during the last 10 or 20 millenia.

The reason for the first could be both phenomena external relative to our planet, such as the intensity of solar radiation and changes in the earth's orbit, and phenomena developing on the planet, such as the formation and movement of the continents and the formation of mountain ranges, volcanic activity, whose products (dust, gases) changed atmospheric transparency, and a number of others.

Climatic changes over the course of recent millénia, whatever factors may have caused them, occurred with maintenance of the earth's orbit, the structure of the earth's surface (positioning of the continents and oceans, mountain ranges, etc.) and, in all probability, with retention of the very same nature and intensity of solar radiation. This makes it possible to assume that on the earth, with its present-day structure, there may exist not one, but several states of equilibrium of the entire complex of hydrometeorological processes transpiring in the atmosphere and ocean, that is, climates somewhat differing from one another. It can also be assumed that a transition from one state to another occurs under the influence of relatively insignificant factors. Complex direct and reversible relationships among all climate-forming processes make it possible to consider possible the appearance, in some cases, of self-developing reactions and triggering effects. An evaluation made by one of the outstanding Soviet climatologists, M. I. Budyko [1], shows that the present-day climate and climates similar to it are in general unstable. In his opinion, two types of climates have a stable character: uniformly warm, characteristic for the Mesozoic, which, as indicated above, lasted for several hundred million years, and a complete glaciation of the entire earth, which evidently never occurred in the earth's history.

In the opinion of some researchers, the principal reason for both major climatic changes in the past, which was mentioned before, and the relatively rapid alternation of glaciations in the Quaternary, is the changing intensity of volcanic activity, accompanied by the ejection of dust into the atmosphere and changing its transparency; in the opinion of others, it is changes in the earth's orbit, etc. The objective of this article does not include an analysis of such hypotheses. It is important for us to emphasize that climate during the course of the entire history of the planet changed under the influence of some natural factors, and therefore there is no basis for assuming that there cannot be such changes in the future. During recent years many publications have appeared in the scientific and general literature on the tendencies seemingly appearing at the present time (1960's-1970's) to a systematic and relatively very rapidly developing cooling in the northern hemisphere, corresponding to a restructuring of general circulation of the atmosphere, major changes in the quantity of precipitation in different zones of the earth, etc. It should be said that a careful analysis, carried out by many scientists, in particular, a large group of Soviet scientists, indicated that such assumptions have no basis. In the next few decades, in our opinion, it is possible to expect small climatic changes, similar to those which have occurred during the last 100-200 years.

Anthropogenic Climatic Changes

The modification of nature is an invariable property of human society, like any other group of living creatures. Mankind could not develop without transforming elements of the environment. The principal forms of modification, which are of the greatest interest for the considered theme, in our opinion, are:

a) Transformation of structure of the planetary surface in connection with the cutting of forests, plowing of the steppe, melioration, formation of large reservoirs, allocation of considerable sectors of the earth's surface for the construction of different structures, etc. Such a transformation changes the reflectivity of the earth's surface and its "roughness," which has an effect on the energy balance and local peculiarities of atmospheric circulation.

b) Transformation of the moisture cycle. An ever-greater part of the runoff of rivers is being expended on irrigation and the needs of production, as a result of which there is an increase in evaporation on the continents and a decrease in runoff into the ocean. Evidently, as time passes all the runoff of rivers will be used for these purposes. This will not change the general cycling of moisture on the planet, but the relationship of its elements in different geographic regions will be different, which will cause a corresponding redistribution of elements of the atmospheric heat regime.

Evaporation, condensation and crystallization of moisture are, as is well known, important elements of the atmospheric energy balance.

c) Transformation of the energy balance. The heat balance of the "earth-atmosphere" system changes both in connection with the change in atmospheric transparency, the principal role in which is now being played by the carbon dioxide released during the combustion of fuel,and as a result of the direct release of heat in the production of electric energy and the consumption of all types of energy on the earth.

Since the system of climate-forming processes in a rough approximation can be equated to a heat engine, it is evidently changes in elements of the energy, especially the heat balance, which are of the greatest importance in possible climatic changes. Local (over areas of about 10,000-100,000 km^2) anthropogenic climatic changes have already been noted. For example, in cities the temperature is somewhat higher, near reservoirs the wind is stronger and the annual variability of temperature is less, etc. However, at the present time it is still not clear what level of change of some particular element of climate-forming processes is adequate for the modification of climate on regional and global scales. What may be the consequences of modification are also unknown.

Most researchers feel that the principal factor in the anthropogenic modification of climate is the release of carbon dioxide in the process of combustion of fuel, the transformation of the planetary cycling of this gas and an increase in its atmospheric concentration, which will increase the so-called "greenhouse effect." Budyko [1], Bolin [4], Bass, Heller, Allston and Rotti [3], Flohn [5] and many others assume that the maintenance of the present-day rates of growth of energy production due to the combustion of fossil fuel will lead to an increase in the CO_2 concentration in the atmosphere by several tens of percent after 50-100 years, which in turn will cause an increase in atmospheric temperature and substantial climatic changes.

In many cases in both the popular and scientific literature the opinion is expressed that an increase in the carbon dioxide concentration, as well as the direct release of heat, in general will lead to a more or less uniform increase in the temperature of the lower layer of the atmosphere, which in turn will cause a general warming, melting of glaciers, etc. However, from our point of view this is not so simple. A temperature increase, being manifested to the greatest degree in the Arctic, will decrease the temperature difference between the polar regions and the equatorial zone. This should in some way change the general nature of atmospheric circulation, for example, lessen the flow of moist air flowing from west to east, from the ocean onto the European continent, etc. For the time being it is impossible to evaluate what will be the consequence of this change, and in this connection, what climate will be established in different parts of the earth. In any case it is difficult to expect that this will be only a uniform warming over the earth's entire surface.

Another hypothesis, frequently encountered in the literature and from our point of view equally unsubstantiated, is that climatic changes can be caused only by a change in the total heat balance of the planet, associated with the use of fossil or atomic fuel. From this point of view, the broad use of direct solar energy, the energy of the wind, rivers, etc. will not play a role. However, not only a change in the entire heat balance of our planet, but also a redistribution of its component elements over the earth's surface, that is, the sources and places of heat consumption, their strengthening or weakening, will inevitably cause climatic fluctuations.

In this connection it is of great interest and importance to examine changes on regional, and possibly on global scales, caused by a further growth of the existing major sources of heat, whose influence is already appreciable in the local characteristics of climate. It can be postulated that the further development of large industrial regions (such as almost all of Western Europe, the southeastern United States, the middle part of the eastern shores of Japan), accompanied by an increase in the energy used by several tens of times, will have the result that they will become similar to natural centers of atmospheric circulation. Some estimates of the consequences of the increase in heat released by this type of sources (they are frequently called "heat islands") have already been made. As one of the examples we can cite a study by Hafele, et al. [6], whose authors calculated that the construction of two major centers for power production (for example, thermonuclear complexes), one near the shores of Great Britain, and the other along the western shores of the Pacific Ocean, in the Canton region, would cause a change in atmospheric circulation over the southern part of the European continent capable of shifting zones of precipitation, which would cause frequent droughts in some regions and abundant moistening in others.

Recently many studies have also appeared which contain estimates of the additional heat, beginning with which a change in the general circulation of the atmosphere could begin, leading to the transformation of climate on regional and global scales. According to most of these estimates, the additional heat of anthropogenic origin, constituting about 1-2% of the heat received by the earth from the sun, or the release of heat over great sectors of the earth's surface, on the order of a million square kilometers, leading to an increase in the mean temperature in this region by several degrees, already can exert an influence, at least on the regional characteristics of general circulation of the earth's atmosphere. At the present time the greatest attention in the problem of the influence of man's activity on climate is being devoted to the increase in energy production, but without question, other forms of transformation of the medium, the environment, by man in one way or another are reflected in climate.

With respect to the quantitative estimates, it goes without saying that they are of an extremely approximate character, but on the basis of present-day knowledge of climate-forming processes it can be asserted with adequate assurance that the present-day activity of man is already leading to appreciable, although local, changes in some characteristics of climate and that with a further increase in energy production by several tens of times (as is entirely possible in the course of the next 100-200 years) climatic changes will begin on a regional and then on a global scale.

Purposeful Modification of Climate

The possibilities and means for purposeful modification of climate have been discussed in science over a long period of time. As is well known, the most different points of view are being expressed on these questions. In our opinion, it is of interest to examine whether in principle it is possible to bring about a purposeful transformation of climate, how this can be accomplished and what the purpose may be.

If the considerations on inadvertent anthropogenic changes expressed earlier are correct, in principle it is evident that purposeful climatic changes are also possible. It goes without saying that for their accomplishment it is necessary to have a quantitative theory of climate which would make it possible to plan and compute the measures required for the intended transformations. The creation of such a theory cannot be regarded as an impossible scientific task.

Since, as mentioned above, the totality of climate-forming processes can be equated to some heat engine, the changes in whose operation most frequently can be associated with deviations in the values of its component elements, then by creating such changes intentionally we could cause similar transformations of different climatic characteristics. For example, in all probability, it would be possible to bring about climatic changes, redistributing the gains and losses of heat at the earth's surface, for example, by constructing major centers for producing and using energy in some places suitable for this and appropriately regulating their work.

In definite regions over a great area it is possible to change the albedo, which, as was mentioned above, would exert an influence on the heat balance. Some researchers, for example, propose for this purpose the creation of thin films on the ocean surface. (Incidentally, contamination of the ocean by petroleum already creates such a film.) It is possible to reduce atmospheric transparency on a regional and even on a global scale by saturating its upper layers by different aerosols. Independent calculations by different scientists indicate that both a change in albedo over great areas in the polar regions and the discharging of aerosols into the upper layers of the atmosphere could be brought about even at the present time if for this purpose use was made of a considerable part of the civil aircraft of several countries for some time. However, it seems irrational to decrease the receipts of solar energy at the earth for the purpose of balancing the increase in energy production on our planet.

It is assumed that one of the means for modifying climate is intervention in the dynamics of the atmosphere or ocean. It is known that mountain ranges exert a considerable influence on the climate of both adjacent and remote territories. It is possible that not particularly grandiose, but specially constructed apparatus, for example, for deflecting air currents upward, could play the same role, since when there are vertical movements of air masses positive feedbacks and self-supporting reactions can arise. It is known that spontaneous deviations of sea currents from their normal trajectories cause substantial changes in the nature of weather. Such, for example, is the effect of the sporadic deviations of the small current El Nino along the shores of Peru. A long-term change in the trajectories of currents could be brought about by the creation of special hydraulic structures. They would have dimensions a thousand times greater than present-day dams, but there are no fundamental obstacles to this.

It would be possible to mention some other fundamentally possible ways to bring about the purposeful modification of climate. Long-term and significant transformations of the heat balance, as well as the dynamics of the atmosphere or ocean, which were mentioned above, without fail introduce changes into the general circulation of the earth's atmosphere. However, taking into account the extremely probable instability of climate-forming processes, it can be assumed that even a brief, one-time intervention can lead to irreversible changes in circulation. Thus, according to the computations of a number of scientists, the one-time annihilation of a considerable part of the ice cover in the Arctic Ocean can restructure atmospheric circulation in such a way that it will never be restored. This would lead to substantial climatic changes on a global scale.

The evaluation of the possibility of inadvertent climatic changes, as well as formulation of methods for its purposeful transformation, insistently requires a study of the possible limiting values of different forms of modification of meteorological processes in which irreversible changes in atmospheric circulation would be excluded.

It is necessary to examine from the social and political point of view the question as to whether it is possible to have a climatic change in some definite region of the earth or over the entire earth as a result of the actions taken in any other limited region. In other words, can some country, by the actions taken in their territory, somehow exert an influence on the climate of another country situated in a different region of the earth. This seems improbable to me. Climatic changes (climate, not weather) on a global scale can probably be brought about as a result of the joint actions of many countries situated in different regions of the earth.

However, there are other opinions. For example, the leading American scientist E. Teller, 20 years ago considered it possible to modify climate for military purposes [2]. For this reason the proposal made by our country in 1972 that an international agreement should be concluded on the banning of modification of the environment for military purposes was entirely timely, and the ratification of this agreement by many countries, which has already taken place, cannot but cause support from scientists working in the earth sciences field.

Thus, from our point of view climate in the future can be transformed as a result of man's purposeful actions. It goes without saying that it is entirely possible that the means for modifying climate will not be used for the purpose of transformation, but rather for the stabilization of the presently existing climate, since the economics and the entire life of mankind have been adapted to it.

Influence of Climatic Changes on Mankind

Climatic conditions and their changes always exert an appreciable influence on man. This feeling is shared by all specialists, but the points of view regarding specific peculiarities of this influence may be different.

I. P. Gerasimov feels that climatic changes in the geological past were the principal factor governing the nature, and in particular, the rates of development of our remote ancestors, and possibly was the factor responsible for the separation of "thinking man" from the animal world. The well-known American geographer Huntington in his time postulated that natural conditions, and climate in particular, determine all the peculiarities of economics, the technical and cultural level, and even the social structure of society, which are under their influence.

We have already cited the example, well known from history, of the death of the Scandinavian colonies in Greenland as a result of the onset of a small glacial period. The expansion and contraction of desert zones in different regions of the earth have repeatedly led to the disappearance of societies and civilizations extremely well developed for their time. Fluctuations in the level of the Caspian Sea, repeated each 200-250 years, introduced substantial changes into the life of the peoples populating its shores. Even brief (lasting one or two years) deviations of meteorological elements from the norm, as is well known, can result in severe, if not catastrophic consequences for many peoples. An example of this is the recent drought in the Sahel region.

In addition to what has already been said at the beginning of this article about an increase in the "sensitivity" of modern civilization to the values of environmental parameters, it must also be taken into account that scientific and technical progress will enable us to live and act under more and more extremal environmental conditions, and the increase in the numbers of population and the growth of production and consumption will make this necessary. At the same time, in such a situation even relatively small changes in natural conditions can lead to far-reaching consequences. For example, if almost all the runoff of a major river is used for irrigating agricultural fields, by virtue of natural factors a decrease by possibly 15-20% can result in a marked decrease in food production in this region. From this point of view our ancestors had lesser possibilities but greater reserves.

It is scarcely necessary to cite further examples of the effect of changes in climatic conditions on human activity; they are well known and have the most diverse forms. Changes in temperature, cloud cover and the quantity of precipitation first of all affect agriculture. Temperature changes in different ocean areas exert a significant influence on fishing, etc. The close relationships which now exist among different branches of economic activity within each country and also the relationships intertwining the economic processes of many countries with one another have the result that an effect on any one branch of economic activity inevitably will lead to far-reaching consequences in the entire economy of a large region and even the entire earth. It therefore follows that the prediction of the future state of climatic conditions on the earth for tens of years in advance and the use of such a forecast for the planning of future actions have even now acquired enormous importance. This is becoming increasingly understandable not only to professional climatologists, but also to political and economic leaders and a wide part of the population in any country.

Mankind's Strategy.

Future climatic changes are inevitable. They are becoming appreciable and may be irreversible in the next few decades. They will have a local, regional and global character.

In this connection it is obvious that it is necessary to formulate some strategy, that is, a system of preplanned long-term actions which for mankind would ensure the avoidance of negative consequences of possible climatic changes. The implementation of a program for such long-term measures should possibly begin in the next few decades. If small local changes in climate can be caused, and evidently prevented by measures carried out in the very same region, in one country, then regional and especially global climatic changes must involve global circulation of the earth's atmosphere. Accordingly, in this case the strategy must provide not only and not so much for local effects as for measures undertaken on a regional and on a general planetary scale.

What are the principal elements of such a strategy? It goes without saying that the first and foremost is prediction of climatic change. This is a very complex problem in natural science. It requires the formulation of a quantitative physical theory of climate, the creation of methods for computing its changes under the influence of different agents.

As is well known, ever-increasing importance is being attached to work on these problems. A rapidly increasing number of scientists are being drawn into this work. Although the problem is exceedingly difficult, in our opinion the situation is not hopeless. Science has always solved problems which have become timely for mankind. Proceeding on this basis, and also taking into account that ways are even now being projected for solving these problems, we can be sure that the natural science aspect of the problem will be solved, although this will probably require much time.

It is also necessary in the future to have a very high degree of international scientific cooperation because the collection of the global information is needed for computing climatic changes, creation of theories, requiring, in particular, the use of the very largest electronic computers, the checking of theories by means of global scale experiments. All this is possible only if there is a well-developed international scientific cooperation. We already have some experience in carrying out such programs. Such was the Atlantic Tropical Experiment GARP, and such also is the planned and already initiated program of the First Global Experiment and some other international scientific investigations.

The second element of the strategy is an evaluation of the consequences to which different natural or anthropogenic climatic changes can lead. Here the natural science problem is closely intertwined with the socioeconomic problem. The influence of climatic changes on economics, like the influence of economics on climate, is being evaluated for the future. Accordingly, the future economics of any country must be taken into account in this case. For example, it is necessary to know what characteristics agriculture, the water use system, all industry, etc. will have after several decades. Only in this case will it be possible to evaluate both the possible anthropogenic changes in climate and the consequences of the predicted climatic changes on human activity. Such an evaluation is possible only on the basis of an allowance for the long-term plans for the development of a country, region, world and mankind as a whole.

The socialist and many developing countries also have long-range development plans. It goes without saying that these plans are still not perfect. Sometimes the planned development of some branch of the economy occurs more rapidly than was intended, sometimes more slowly. But in one way or another the planned measures are being put into practice. However, many countries do not have prepared complex plans and their development resembles a random process. Accordingly, future activity and the state of different branches of their economy can be evaluated in the form of a singular "forecast."

Then, in order to evaluate how favorably or unfavorably the climatic changes may exert an influence on different branches of the economy of a country, a region or the entire world, we must settle on some definite point of view. It must be determined what is good and what is bad. From what point of view should we evaluate the effects of climatic changes on the economy? From the point of view of an individual firm or large monopoly, from the point of view of the inhabitants of a particular city or the entire population of the country, or, finally, all mankind? In selecting the point of view we must take into account not only the direction and prospects for development of the economy, but also its purpose. For achieving what goals can climatic changes be favorable? I scarcely will error if I say that most scientists consider this purpose to be the vaguely expressed "welfare of all mankind." However, this is a very complex matter.

A number of economists and sociologists rather recently published studies in which they endeavored to delve into this problem. Such, for example, was a study by a group of scientists carried out under the direction of the well-known American economist Laszlo [7]. In this study he investigated the goals which different countries in the world were striving for, the goals which have been set by the governments of different countries, different groups in the population, international organizations, religious societies, etc. Laszlo was forced to draw the conclusion, obvious for us, that the real goals of the countries, to which are really directed all the economic and other activity of the peoples and governments, exist in the socialist states which are planning and directing their development. With respect to the capitalist countries, such a concept does not exist there, there being only wishes with respect to the further path of development, different for different organizations and population groups. Naturally, there are no definite goals or plan for their attainment by mankind as a whole. Laszlo calls for the development, adoption and pursuit of some goals rational for all mankind, to a "revolution of goals," as he expresses himself.

The third element of the strategy is the formulation of recommendations on such measures as would make it possible to avoid negative consequences of climatic changes or to avoid the changes themselves. Such recommendations are being developed even now and are being set forth in the studies of very many scientists. For example, it is frequently proposed that there be a sharp reduction in the use of fuel for obtaining energy for the purpose of avoiding an increase in atmospheric content of CO_2, that measures be adopted for increasing the absorption of carbon dioxide by the biosphere, that there be a restriction on the production and consumption of energy in general for the purpose of maintaining the heat balance.of the planet, etc. Some scientists in rather outspoken form express their fears that in the event that such recommendations are not implemented mankind will have to contend with dangerous climatic changes in the next 50-100 years. For the most part the recommendations are directed to the maintenance of present-day climate, although some also feel that it can be changed in a "better" direction.

However, to whose address are such recommendations directed and who should implement them? Most frequently they mention "politicians" or some "policy makers." It should be noted that virtually all the studies of western scientists devoted to this problem end with an appeal to the mentioned individuals. Appeals to "policy makers" are not by any means being made only by climatologists at the present time.

Possible climatic changes constitute only one of the so-called "global problems" with which mankind is now faced. These problems include those of ensuring the world's entire population with food, reduction of the currently existing gap in the economic, technical and other levels of the developed and developing countries, methods for producing energy, rational use of water resources, resources of the ocean and space at a planetary scale, and a number of others. An ever-increasing scientific literature is devoted to this subject. From our point of view it is important that the authors of all the investigations arrive at the conclusion that there is a need for common, globally correlated measures of many countries in order to solve each of these problems and their totality.

The recommended measures vary. For example, the Meadows group, in the widely known study THE LIMITS TO GROWTH [9], mentions the need of stopping all the development and growth of mankind. Mesarovic and Pestel [10], improving the computation method, conclude that development is possible, but that it must be correlated on a planetary scale. The well-known American economist W. Leontiev, and a group of specialists [8], shows that within the existing natural framework the development of mankind is possible in accordance with several scenarios, although he does not say how to ensure the sequence of any of them. A large group under the direction of the well-known economist Tinbergen [11] gives recommendations on the formulation of a "new world order," a new system for interaction among countries at a planetary scale, such that the economy of the countries and all their activity as a whole will be guided by some supranational center to which the governments must delegate some of their sovereign rights. Incidentally, Tinbergen mentions "policy makers," on the basis of whose agreement the desired restructuring of the world order could be brought about. Such, in his opinion, are: the governments of countries, international organizations (especially the UN) and multinational monopolies.

We will not examine here the interesting and important matter of the goals, stimuli and methods for controlling the economy of countries. We note only that they are extremely different in countries with different social systems. Nevertheless, the correlation of measures by different countries over our entire planet for the purpose of moderating and then solving the developing global problems of modern civilization is even now very important and is becoming completely necessary in the course of the next few decades. It can be achieved only by the cooperation of sovereign states on the basis of equal rights and mutual advantage. Such a correlation of measures and cooperation is taking place even now in fields where the interests of different countries coincide. The World Meteorological Organization has been active for more than a hundred years. The World Health Organization and many others are successfully operating. Cooperation is developing in the field of preservation of the environment, agreements have been concluded on the banning of modification of the environment for military and hostile purposes, on prevention of oceanic contamination, etc.

It is very important that in examining different problems, we approach one and the same thing from different sides: an understanding of the need for intensifying and strengthening international cooperation. It goes without saying that the cooperation of different countries in the solution of global problems, for example, in preparing mankind for the consequences of possible climatic changes, is immeasurably more complex than in the activity of the World Weather Service. However, it is still more necessary. And the process of relaxation of international relationships, developing during the last decade despite all the resistance of its opponents, inspires in us an assurance that cooperation will come about in the most different fields.

The adaptation of the world economy to new climatic conditions, and in particular, the purposeful modification of climate on a global scale with adherence to some mandatory conditions, is possible. The most important of these conditions are as follows:
-- prevention of a world conflict and the establishment of a stable and durable peace, since only under conditions of peaceful co-existence of countries with different social systems is it possible to cooperate closely and carry out the correlated global-scale measures, whatever they may be;
-- cessation of the arms race and disarmament, since only in this case is it possible to allocate great material resources for carrying out the necessary measures.

It is easy to understand that the solution of any other global problems of modern civilization is also possible only with adherence to these conditions.

I am not sure that at the present time we will attain agreement on precisely how climate will change in the next few decades, but I assume that we will all be unanimous in that mankind must formulate a definite strategy in making ready for climatic changes and that peace, disarmament and cooperation are the basis for such a strategy.

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MODELING OF CLIMATIC CHANGES AND PROBLEMS IN LONG-RANGE WEATHER FORECASTING

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[Article by Academician G. I. Marchuk, Computation Center Siberian Department USSR Academy of Sciences, submitted for publication 13 March 1979]

Abstract: This is a concise review of investigations and problems in the field of numerical modeling of general circulation of the atmosphere and ocean, climate and numerical methods for long-range weather forecasting. The author sets forth a new approach to the problem of long-range weather forecasting and evaluation of climatic variations. An international long-range program is proposed for investigations of interaction between the atmosphere and oceans for the purpose of long-range forecasting of weather and the theory of climate.

[Text] World Ocean and Its Role in Climate Formation. In a study of climate it is important to know what changes or fluctuations it experiences and in the course of what characteristic time scales; this may be thousands, hundreds or tens of years. Accordingly, we must deal with epochal, secular or so-called "local-time" climates. Each of these climates has its own temporal and spatial scales for the averaging of fields of meteorological elements.

In a report entitled "Physical Principles and Modeling of Climate" [22] it was emphasized that "...the physical processes responsible for the formation of climate are the same as in weather phenomena."

The most important of these processes is the rate with which heat enters into the climatic system, the only source of which, to be sure, is solar radiation. The atmosphere and ocean react to this heating by the development of systems of winds and currents which transport the heat from regions where it is received in excess to regions with a deficit of thermal energy.

Whereas physical processes in the atmosphere, lasting from 10^{-1} to 10 days, for the most part determine weather phenomena, processes in the ocean with time scales from 10^{-1} to 10^3 years are responsible for climatic variations.

Estimates reveal that the heat flows in the atmosphere and ocean directed toward the poles are comparable in magnitude. This means that the world ocean plays an important role in the formation of climate and its changes.

At the present time we know of a number of mechanisms determining the influence of the oceans on the atmosphere [5]. In his interesting empirical investigations Bjerknes [18] established a correlation between long-range temperature anomalies of the Pacific Ocean surface in the tropical zone and the system of winds in its northeastern part. These anomalies are evidently a result of weakening of the Trades in the southern hemisphere, and accordingly, equatorial upwelling.

Wyrtki [44] studied the influence of anomalies in the Trades field in the western part of the Pacific Ocean on the subsequent long-term anomaly of ocean circulation in the eastern part of the Pacific Ocean. These investigations made it possible to explain the El Nino effect as a result of weakening of upwelling due to weakening of the Trades.

Namias [34] studied the effect of long-term anomalies of ocean surface temperature in the middle latitudes during the summer seasons on atmospheric temperature anomalies on the North American continent in the subsequent autumn and winter seasons.

Musayelyan [11] discovered asynchronous correlations between anomalies of summer cloud cover over the North Atlantic and winter air temperature anomalies over the European continent.

Fletcher established the presence of atmospheric anomalies which could be detected over considerable distances and over time periods up to eight years. It can be assumed that they were propagated through the world ocean.

However, the enumerated mechanisms of the influence of anomalies of ocean surface temperature on the atmosphere possibly constitute only the simplest cases of long-term thermal effect of the ocean on the atmosphere.

In general outlines, the process of formation of long-term temperature anomalies can be represented in the following way [8].

Cloud systems are formed over the oceans. If the cloud cover is less than the climatic norm, it transmits more solar radiation and the surface water layer is heated more intensively. If an anomalously weak cloud cover sets in for a period of about a month or season, a considerable heating of the ocean is observed in this region. The heated waters are transported by currents into the northern regions of the Atlantic and Pacific Oceans. They reach regions where in the surface layer of the ocean, under the influence of low air temperatures, a zone of vertical instability is formed. This leads to powerful convective movements which transfer the accumulated heat from the deep layers of the ocean into the atmosphere. This heat heats the air in a particular region. The cold polar air near this region creates sharp temperature contrasts, which leads to the genesis of powerful cyclones. The latter are transported to the east by the middle-latitude planetary flow, transporting portions of heat onto the continents and creating zones of warming there.

Evaluation of Climatic Changes and the Sensitivity Problem

There are now two main approaches to the problem of evaluating climatic variations. The first assumes the possibility of substantial climatic variations due to weak stability of atmospheric processes. Under these conditions even with relatively small variations in the parameters the climatic changes can become significant. A quantitative estimate of possible climatic variations in this case requires the formulation of precise models, which are now only being developed. Therefore, in this case the problem is reduced to the possible realization of one or another qualitative picture of climatic changes, which more likely will give rise to new problems rather than solving them.

The second approach [30] is based on the assumption of a relative stability of climate relative to variations of the parameters of the climatic system. This approach assumes that quantitative evaluations of climatic variations based on the theory of perturbations are possible. This will make it possible to attempt to predict climatic trends for several years in advance, using variations of the parameters.

$$L\varphi = F, \tag{1}$$

$$L^*\varphi^* = F^*. \tag{2}$$

Here the first equation can represent in operational form a system of full equations in hydrothermodynamics or, for example, in a simpler case, the heat transfer equation. The second, conjugate equation follows from the Lagrange identity.

Combining these equations and carrying out the necessary transformations, we arrive at prognostic formulas for different functionals: this can be, for example, the mean temperature anomaly over a quite large region:

$$\delta T = f(\varphi, \varphi^*, \delta\alpha_1, \delta\alpha_2, \ldots). \tag{3}$$

This approach to study of climatic variations can be regarded from the point of view of the sensitivity of mathematical models of climate to variations of the input parameters. As such parameters we can use climatic variations of cloud cover, direct radiation, albedo, snow cover, ice edge, etc. "Sensitivity" determines the degree of stability of the system relative to variations of external factors and to changes in the internal structure of models. Human activity can be included in the model as one of the factors in the climatic system, together with other factors of natural origin.

A number of investigations of the sensitivity of a climatic system have been carried out using models with few parameters: Budyko [2], Mitchell [32], Sellers [37], Lindsen and Farrel [26], Schneider, et al. [21], and with models of general circulation of the atmosphere: Mintz, Arakawa [16, 17], Washington [41], Gates, Manabe, Wetherald [29, 43], Schneider, Chervin [21], and others. We will not give a full review of all these investigations here. They have been described in special publications and reports of Doctor Gates, Doctor Mason [31], and others. However, we will discuss the general principles of numerical modeling in investigations of sensitivity.

The authors of the above-mentioned studies employ the direct modeling method, which at the present time is employed most frequently in investigations of sensitivity or response. The essence of this method is as follows. The problem is solved with unperturbed and perturbed sets of parameters and the sought-for parameter is computed as the difference between these solutions. In numerical experiments the direct modeling method is simplest and most universal.

In many cases, however, it is necessary to determine very small variations of functionals of the solution, such as temperature values averaged in time and space. It appears that it is possible to use the direct relationships between variations of the input data and variations of the functionals. These relationships are realized through sensitivity or response functionals.

If as the unperturbed state we take actual information on the basic climate-forming factors, and not solution of a mathematical model of climate, the formulas of the theory of perturbations will enable us to compute small variations of the most important climatic functionals without solving the direct and conjugate problems repeatedly.

In our opinion, this is the main importance of the theory of perturbations applicable to an evaluation of climatic variations.

Climatic Models

During the last 20 years, beginning with a study by Phillips [35] (1956), we have observed an explosion of ideas and methods in numerical modeling of atmospheric processes. It was demonstrated in the mentioned study that despite significant simplifications introduced into the model, it is possible to obtain solutions with a qualitatively correct description of the principal characteristics of atmospheric circulation. We have also come to an understanding of what physical processes are most important to describe in order to more or less correctly reproduce the principal characteristics of the atmosphere. In this field a fundamental contribution was made by Smagorinsky [38] and Manabe [28], Mintz and Arakawa [16], Leith [25], Kasahara and Washington [23], Mason, Gilchrist in their investigations of numerical modeling of general circulation of the atmosphere, and also by Charney [20], Thompson [40], Lorenz [27], Phillips [35], Gates [21], Monin, Obukhov [10], Kondrat'yev [3], Kurbatkin [24] and many others in studies of the physics of large-scale circulations.

Now we will discuss the most typical approaches to solution of these problems. Virtually all the models formulated for describing the atmosphere are based on the full equations of hydrodynamics in a quasistatic approximation, written in different coordinate systems. Numerical (finite-difference and spectral) schemes, used in this case, are usually constructed in such a way that there will be adherence to the same conservation laws which the initial system of differential equations has. Among the many schemes employed at the present time we will note the Arakawa scheme [17], which is becoming popular, which under definite conditions has two quadratic invariants, and also implicit, absolutely stable finite-difference schemes based on the splitting method. Recently preference has been given to higher-order (than second) schemes, but nevertheless, for a good description of eddies it is necessary to have a higher spatial resolution.

An important problem in the formulation of models is parameterization of processes on a "sub-grid" scale, especially convective processes, which are responsible for the development of tropical disturbances. It must also be noted that great attention is being devoted to the parameterization of processes transpiring in the boundary layers, the influence of orographic nonuniformities of the earth's surface and the problem of the upper boundary condition in the atmosphere.

Despite the fact that in the field of modeling of atmospheric circulation there are still many unsolved problems, it can be said with assurance that meteorologists have achieved a high level of understanding of the mechanisms of atmospheric processes.

Whereas in the first numerical experiments with models of general circulation the emphasis was on a qualitative description of the principal properties only of atmospheric circulation, at the present time we are dealing with a quantitative description of the climatic characteristics of the atmosphere and ocean as a coupled system.

It is possible to construct a hierarchy of models created for the modeling of climate and its variations based on a description of the dynamic characteristics of the system. The simplest models (models of zero dimensionality) are models based on the thermodynamic energy balance equation (Budyko, [10], Sellers [37] and others). Despite their simplicity, the "zero" dimensionality models can be used in paleoclimatological investigations, the importance of which has been emphasized in a report by Academician I. P. Gerasimov. [Reference is to the report by I. P. Gerasimov at the World Climate Conference (Geneva, 12-23 February 1979).] More complex first-dimensionality models, so-called convective radiation balance models, allow the introduction of the vertical distribution of atmospheric characteristics (Manabe, Wetherald [29] and others), and in our opinion, make it possible to model the characteristics of secular climate. Using them it is also possible to study effects governed by the dynamics of the upper layer in the ocean.

Since it is impossible to model changes in climate of the atmosphere without describing dynamics of the ocean, the problem of formulating joint models of the ocean and atmosphere is becoming especially important. This will require major computation facilities, since the ocean, having high characteristic relaxation times, also has lesser scales of energetically significant waves than the atmosphere. This, in turn, requires a high spatial resolution.

General ideas in problems of modeling of ocean dynamics have been developed in the investigations of Stommel [39], Munk [33], Sarkisyan [12], Lineykin [6], Welander [42], Robinson [36], Veronis and others. Several numerical models of general circulation of the ocean have been developed on the basis of heat (or density), momentum and salinity transfer equations (Bryan [19], Sarkisyan [12], Kochergin [4] and others). Nevertheless, even specially developed finite-difference schemes do not completely remove the above-mentioned limitations involved in modeling of the oceans.

The next step for a definite class of problems is the formulation of joint models of circulation of the atmosphere and ocean. The pattern of vertical distribution of hydrothermodynamic and turbulent characteristics obtained in joint models of dynamics of the atmosphere and ocean is a result of solution of a closed system of hydrothermodynamic equations. Precisely it can be used for modeling of climatic changes.

Long-Range Weather Forecasting and Evaluation of Climatic Variations

Many investigations have been devoted to the problem of weather forecasting up to two weeks in advance by hydrodynamic methods, beginning with the work of Blinova [1] (1943). Nevertheless, attempts to use different models for forecasting on the basis of initial fields have led to the conclusion that the limit of predictability with these schemes does not exceed two weeks. After repeated confirmations of this fact the conclusion was drawn that a detailed forecast for a time greater than two weeks in general is scarcely possible.

Further investigations by meteorologists demonstrated that there can be other formulations of problems in hydrodynamic weather forecasting which can make it possible to predict some meteorological elements for a period up to a season if we take into account the processes transpiring in the ocean and soil.

For example, Adem [15] developed a hydrodynamic approach to the problem of long-range prediction of temperature anomalies of the land and ocean surface. It is based on integration of the heat influx equations for the ocean, land and atmosphere and a complex parameterization of different physical factors. Encouraging results were obtained by the author.

A number of conclusions follow from an analysis of the characteristic frequencies and eigenvectors of planetary atmospheric dynamics. The analysis made by Yudin is based on use of the asymptotic method for separation of movements in a spectral model with the full equations of atmospheric dynamics [13, 14]. Computations are given with definite conditions to the appearance of very small values of characteristic frequencies. This gives a basis for concluding that the weather of subsequent months can be dependent on the values of the initial phase of "quasistanding" waves and that this dependence is subject to computation.

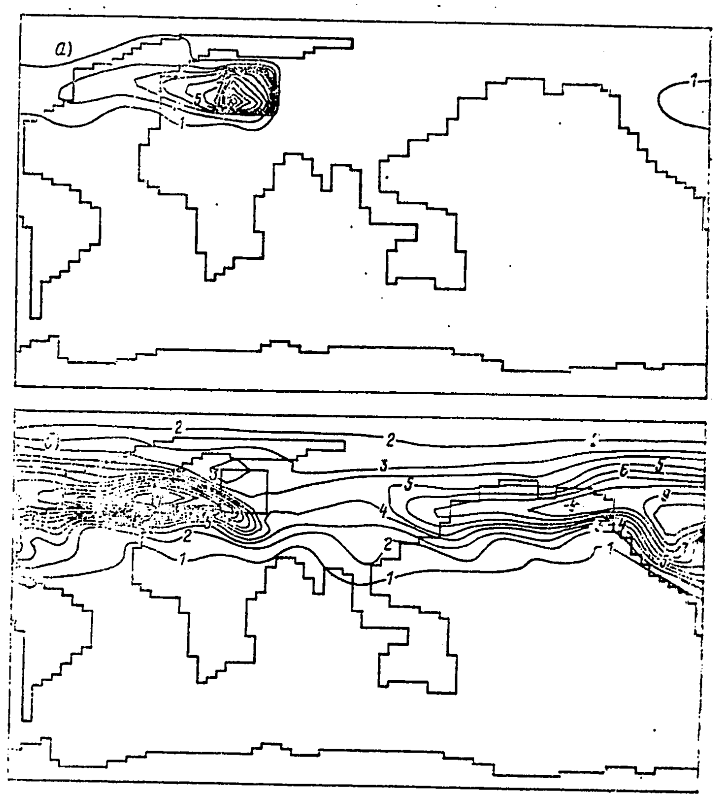

Fig. 1. Isolines of mean monthly values of solution of conjugate problem at the earth's surface for prediction of November temperature anomalies in European USSR. a) first month from beginning of computations; b) second month from beginning of computations.

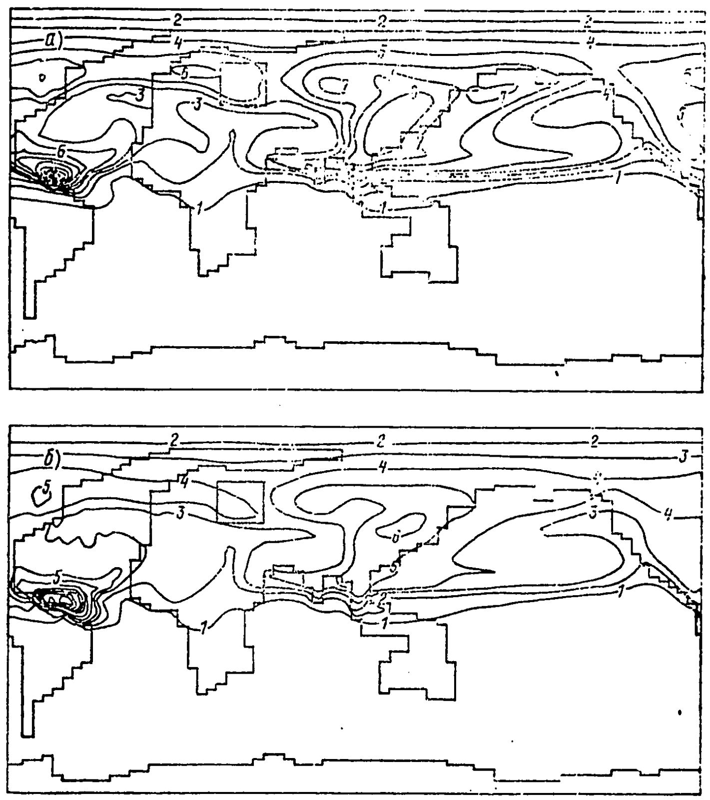

Fig. 2. Isolines of mean monthly values of solution of conjugate problem at earth's surface for prediction of November temperature anomalies in the European USSR, a) fifth month from beginning of computations, b) sixth month from beginning of computations.

The new mathematical approach is based on the use of the conjugate equations of hydrothermodynamics and a specially formulated theory of perturbations [7, 9]. The purpose of these investigations is the long-range forecasting of mean monthly temperature anomalies averaged for large regions of the earth with an advance time from a month to a season. The problem formulated is prediction of the sign of such a temperature anomaly. The thermal behavior of the land and the hydrodynamics of the ocean are becoming the principal determining factors in long-range forecasting.

An algorithm for long-range prediction of mean temperature anomalies, based on integration of the conjugate equations of hydrothermodynamics of the atmosphere and oceans, will make it possible to describe some of the above-mentioned asynchronous relationships. The solution of the conjugate problem is a spatial-temporal function of input meteorological information relative to predictable temperature anomalies. Using influence functions it is possible to determine the most important regions in the world ocean exerting a decisive influence on formation of the mean temperature anomaly over quite large regions of the earth during different seasons.

Now we will examine the results of two experiments for computing conjugate problems (influence functions of radiation flux anomalies) for predicting the mean November temperature anomalies of the surface of the European USSR and regions of the United States. Here we have used the mean monthly climatic data on wind velocities in the atmosphere and the boundaries of snow and ice cover on the earth's surface.

The Antarctic continent and the Arctic Ocean were assumed to be covered by ice. The velocity field of ocean currents was taken from a model of circulation in the world ocean developed at the Computation Center Siberian Department USSR Academy of Sciences.

Figure 1 shows isolines of the mean monthly values of solution of the conjugate problem at the earth's surface, being an influence function. At the top (a) we have shown the results of computations for one month; the zone where the function has a maximum is situated in the European USSR. At the bottom (b) the figure shows the results of computations for two months. Now the zone of the influence function maximum is situated over the northern part of the Atlantic Ocean.

We note that the mean monthly temperature anomaly over the European USSR for the first month is determined as the product of the influence function (Fig. 1a) and the corresponding deviation of the heat flow from the climatic norm, integrated over the entire earth. The mean monthly anomaly for two months is the sum of two effects associated with the influence functions (Fig. 1a and b). To this, naturally, we must add the contribution of the initial fields, rapidly attenuating as the time of the forecast is increased.

In the next figure (Fig. 2) we show the results of computations for five months (at top) and for six months (at bottom). The zone where the maximum of the influence function is situated is the tropical part of the Atlantic, in the region where the Gulf Stream is generated. Here also the mean monthly temperature anomalies for the fifth and sixth months are determined as the sums of the corresponding effects during the preceding months. In this case the contribution of the initial fields can be neglected.

Thus, in the formation of the mean November temperature anomalies over the European USSR an important role is played by radiation processes transpiring in the tropics and subtropics of the Atlantic Ocean. The computations indicated that radiation processes in the tropics and subtropics of the Pacific Ocean are of great importance for mean November temperatures in the United States.

In numerical experiments for summer temperature anomalies for the European USSR and the United States the zones of maximum values of the influence function were displaced northward: into the Iceland region for the European USSR and toward the Aleutian Islands for the United States.

Similar influence functions could be computed for any other regions of our planet. In each case this would make it possible to detect and define more precisely the zones of most active influence on atmospheric processes.

It can be expected that the most important zones of active influence on atmospheric processes in different regions of the earth will be related to a considerable degree to powerful currents in the world ocean and regions of active thermal interaction between the atmosphere and ocean, taking into account seasonal variation and monsoonal circulations for the selected regions.

Now we would like to discuss some problems which can play an important role in the further forming of an understanding of climate and general circulation of the atmosphere and ocean.

It is generally recognized that prolonged changes in the state of the atmosphere are determined to a considerable degree by the process of exchange of energy, moisture and heat in the "atmosphere-ocean" system. However, these processes have not been studied adequately and many oceanographic investigations recently carried out frequently have a random nature and are not specially directed to solution of the problem of long-range weather forecasting and the theory of climate. It seems necessary that the WMO (in cooperation with other international organizations) formulate and implement a program of long-range scientific research work for studying interaction between the atmosphere and ocean for the purpose of creating methods for long-range forecasting of weather and climatic variations. Such a program could become a logical development of investigations and observations carried out and being carried out within the framework of the GARP program.

The principal objectives of such a program could be the following:
-- studying the spatial-temporal variability of the principal characteristics of the ocean and atmosphere over the oceans at time scales from a month to a season;
-- establishing correlations between thermal and dynamic anomalies in the ocean and the formation of circulation anomalies in the atmosphere over the oceans and continents by means of a quantitative determination of all the heat balance components.

These long-term investigations could be carried out on the basis of a system of polygons and sections in several sectors of the world ocean. The observations should be carried out quasisynchronously at a definite time of the year and be supplemented by observations from buoy stations and satellites. The ocean sectors must be selected in regions most sensitive with respect to interaction between the atmosphere and ocean, determining the development of weather processes and phenomena.

Such observations would make it possible, in a relatively short time (5-6 years), to obtain information for developing new and improving existing methods for long-range weather forecasting and cast new light on the physical reasons for climatic variations and changes.

The proposed program rests on two principal concepts.

The first concept uses the approach of conjugate hydrothermodynamic equations and influence functions obtained using this approach. We have already cited examples of numerical experiments with influence functions indicating the role of ocean processes in the forming of large-scale weather phenomena. These results make it possible to indicate those sectors of the oceans where hydrophysical observations must be organized first.

The second concept is a hypothesis which can be one of the possible explanations of the variability of climate and significant weather anomalies.

The basis for the hypothesis is the assumption of the possibility of the prolonged movement of water masses with anomalous temperature values in the ocean. These masses can reach great depths due to the appearance of an unstable stratification and migrate over a long period of time without becoming apparent from observations in the surface layers of the ocean.

Under suitable conditions and over time periods of several months and even years these wave masses can emerge at the surface and cause major anomalies of atmospheric circulation.

A detailed study of zones of active influence in a current over a more or less prolonged period will help in detecting these phenomena if they do exist. This will make it possible to establish correlations between them and the principal atmospheric phenomena.

The Thirtieth Session of the WMO Executive Committee examined the proposal for organizing a research program for study of processes of interaction between the ocean and the atmosphere for the purposes of long-range weather forecasting and the theory of climate presented by the Vice President of the WMO, Corresponding Member USSR Academy of Sciences Yu. A. Izrael'. The committee decided that the proposal has a sound scientific basis.

The Soviet Union has already proceeded to implementation of the proposed program within the framework of its national research program on standard sections in the Atlantic and Pacific Oceans.

Six of the ten sections are located in the Atlantic Ocean and the others are in the Pacific Ocean (Figures 3 and 4).

The observations are being made four times a year in the oceanographic seasons: in February, May, August and November.

These observations constitute part of the investigations being carried out in accordance with international and national programs (GARP, POLYMODE, MONEX, POLEX and others).

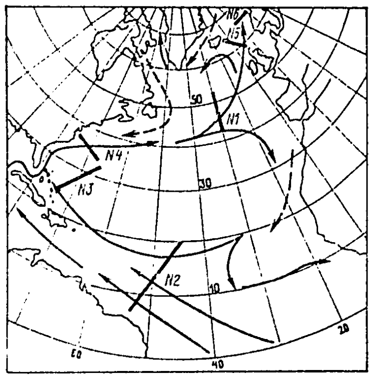

Fig. 3. Map of standard sections in the Atlantic Ocean.

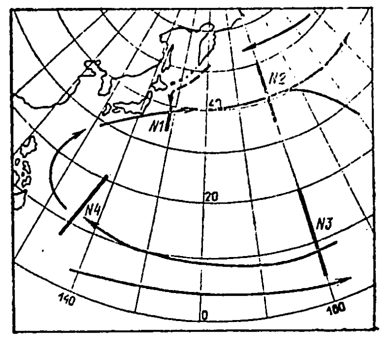

Fig. 4. Map of standard sections in the Pacific Ocean.

It is known that hydrophysical investigations require considerable expenditures and resources. It therefore follows that there is need for joint use of satellites and research ships outfitted with complex measuring apparatus, a network of buoy stations and other means for the collection and processing of data.

As was noted in the important reports of Doctor White and Academician Ye. K. Fedorov, sudden climatic variations inflict an enormous loss on agriculture over extensive areas of the earth, which leads to suffering of millions of people. [Reference is to reports at the World Climate Conference (Geneva, 12-23 February 1979).] It is therefore necessary to draw up major scientific research programs directed to solution of these fundamental problems.

The multisided investigations of the atmosphere and ocean will undoubtedly stimulate theoretical investigations in the field of general circulation of the atmosphere and ocean and the climate of our planet and will bring closer the time when our science will be able to predict climatic variations and long-range weather changes, which will assist in the timely taking of measures for the prevention of calamities and in improving the life of mankind.

[Note: This is the basic content of a report at the World Climate Conference (Geneva, 12-23 February 1979).]

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CLIMATES OF PAST GEOLOGICAL EPOCHS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 37-53

[Article by I. P. Gerasimov, Geography Institute USSR Academy of Sciences, submitted for publication 25 April 1979]

Abstract: This article sets forth the methods and initial data used in paleoclimatic reconstructions. The author generalizes the experience from investigations carried out earlier. For a number of time limits, making it possible to reconstruct the scenarios of future climates, the article gives the characteristics of past climates. Among such time periods it is possible to define the preglacial period, the last interglacial epoch and the period of the climatic optimum of the Holocene. As a contrast, the climate of the coldest phase of the last glaciation is described. [This is the basic content of a report at the World Climate Conference (Geneva, 12-23 February 1979).]

[Text] The science of climates of past geological epochs -- paleoclimatology -- has now acquired extremely timely importance. One of the reasons for this is the growing restlessness of the world community about the possibility of major changes in present-day climate and the influence of these changes on the state of the environment. Modern paleoclimatology is the study of past climates on the basis of paleogeographic data, detection of a natural trend, a reconstruction of these climates, long-range climatic changes and analogues of probable types of climates of the future. In this way the possibility arises of an additional validation of climatic forecasts and the checking of physical-mathematical models.

However, the problem of creating reliable reconstructions of past climates is not simple. First, these reconstructions are based on indirect data, incomparably more limited in comparison with the data used in studying modern climates. Second, they are based on use of a methodology which to a considerable degree has a stochastic character.

The basic information on climates of past years is obtained by an ecological interpretation of paleobiological data, that is, macro- and microresidues of plants (including pollens and spores) and animals (bone and shell remnants), buried in geological deposits of different age on the continents and on the floor of the seas and oceans. This basic information is supplemented by a study of the genetic types of ancient fossil soils, weathered crusts and lithoclimatic facies of continental deposits (for example, laterites, kaolins, bauxites, loesses and others), lacustrine and sea (including abyssal) sediments. Considerable paleogeographic (including paleoclimatic) information is also provided by historical and archeological materials. The use of geochemical (primarily isotopic) methods in paleoclimatic investigations has recently begun and is rapidly expanding. Among these absolute datings, and paleotemperature measurements in the remnants of microfauna, shells of fresh-water and sea mollusks, bone remnants, samples of ancient ice, etc. are acquiring particularly great importance. The volume of this information is rapidly increasing, although it still remains inadequate. For definite paleogeographic situations it is also possible to use models of the general theory of climate for paleoclimatic reconstructions. On the basis of the introduction of appropriate boundary parameters into such models it is possible to reconstruct theoretically the meteorological regimes of past geological epochs.

In the sphere of study of climates of past years it is feasible to distinguish at least three principal fields of research: climatology of the present-day period, climatology of the historical period and climatology of past geological epochs or paleoclimatology proper. In addition to different time intervals, each of these fields of research uses different initial data. Modern climatology deals with the results of direct meteorological observations and covers the period of a hundred years before our time. Historical climatology is based on records and old manuscripts, describing different meteorological phenomena, and also on a study of those natural objects which contain precise chronological data (for example, dendrochronology). This field of investigations already covers several thousand years. Finally, paleoclimatology operates, as was mentioned, using diverse paleogeographic and primarily paleobiological data. It covers millions of years.

This article deals only with the subject of paleoclimatology.

Traditional paleoclimatic reconstructions are based on an actualistic method. This principle is based on the concept that ancient species of plants and animals, used as paleogeographic indicators, imposed on the climatic conditions of past geological epochs the very same requirements which are characteristic for related or modern species of organisms. The same also applies to ecosystems (biocoenoses), and also to weathered crusts, soils, lithoclimatic facies of continental deposits, etc. With its application some paleoclimatic characteristics can be expressed in quantitative indices.

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Thus, for example, geographic zonality is associated with the indices of the thermal energy base (radiation balance of the earth's surface) and moistening conditions for all the main modern macrotypes of natural ecosystems (Table 1). Taking this dependence into account, using data on geographic zones of the past it is possible to establish temperature characteristics and atmospheric humidity values corresponding to these zones. In paleoclimatic reconstructions it is also possible to use climatic parameters characteristic of the conditions for formation of present-day weathered crusts, soils and lithogenetic facies of continental deposits, and also the optimum conditions for the existence of individual species of plants and animals, their groupings and complexes (Table 2). During recent years it has become possible to determine the temperature conditions for the existence of plankton complexes in the world ocean.

Naturally, all this creates a rather broad basis for paleoclimatic reconstructions, although sometimes it causes doubts from the evolutionary point of view, since modern plants and animals in many cases have a relatively recent geological age. Their predecessors, that is, more ancient, and especially disappearing species, could impose both similar and different requirements on climatic conditions. True, there is a possibility, by means of study of the morphological peculiarities of dead organisms, to compare them with modern organisms and on this basis draw various paleoecological conclusions (for example, affinity to heat, xeromorphism, etc.), but such conclusions usually have only a probabilistic character.

At first glance it may seem that more indisputable quantitative paleoclimatic information is given by the use of the latest geochemical methods. However, such information is usually developed on the basis of definite theories based on the regularities of modern natural phenomena. For example, data on paleotemperatures, based on the relationships of oxygen isotopes, proceed from the assumption that the chemical composition of ocean waters in the past did not differ from that of today. The same can be said about carbon dating and the gas composition of past atmospheres, although some historical geology corrections are introduced into it. Thus, the latest methods for obtaining paleoclimatic indices to a considerable degree are also actualistic.

As indicated by already accumulated experience from paleogeographic reconstructions, their reliability is increased when obtaining similar results by methods which are independent of one another: paleolithological, paleopedological, paleobiological and others, supplemented and checkable by geochemical (isotopic determinations) and geophysical methods (physical modeling on the basis of application of the theory of climate).

At the same time, it must be emphasized that as a result of the considerably lesser paleogeographic information which is available for more ancient geological epochs, and also by virtue of the increasing limitations in the application of actualistic principles and use of models in the theory of climate, the general degree of scientific validity of paleoclimatic reconstructions is decreased as one goes back in geological time.

Therefore, for more ancient epochs there is also a decrease in the prognostic role of the corresponding paleoclimatic reconstructions.

The reconstructions made using traditional methods of paleogeographic investigations made it possible to arrive at a number of important paleoclimatic generalizations. The most important of these is the idea of a predominance, during the course of the entire Mesozoic and part of the Cenozoic eras, of relatively hot climates at the earth's surface with poorly expressed seasons and on the existence of broad natural zones with different moistening levels. At the same time, it was possible to detect a general tendency to cooling -- over the course of the Cenozoic -- of the climates in the temperate and high latitudes with an increase in the contrast of seasons, and also to successive complication of natural zonality, which led to an increasing diversity of the earth's climates. This tendency was complicated by cyclic variations in climatic conditions with a different amplitude.

Such is the general picture of paleoclimatic conditions of the Mesozoic-Cenozoic following from the widely known studies of E. Huntington and S. S. Visher (1922), W. Köppen and A. Wegener (1924), C. Brooks (1926-1950), F. Kerner-Mailaun (1930), N. M. Strakhov (1948), M. Schwarzbach (1950), V. M. Sinitsyn (1966) and other authors.

It should be noted that the specific presentation of the described general pattern of paleoclimates of the Mesozoic-Cenozoic in these studies, and also in many others was substantially different. This is attributable both to many difficulties in the interpretation of paleogeographic information and the need for using a generalization of empirical data from different theoretical historical geology models. It is especially important that in many investigations of climates of the past the basis for paleogeographic reconstructions is a model of a permanent positioning of the continents and oceans (Brooks, Schwarzbach, Strakhov, etc.). As is well known, an exception is a study by A. Wegener and W. Köppen (1924) in which the theory of continental drift (and also migration of the poles) was advanced for the first time.

At the present time the theory of continental drift (and also migration of the poles) or the so-called theory of global tectonics of plates is being used more and more widely for explaining many events in the earth's geological history. According to this theory, already at the end of the Mesozoic there was a single land mass (Pangaea), surrounded by the world ocean. During the course of the Mesozoic-Cenozoic the Pangaea land mass was broken down into a number of continental blocks which moved apart and formed the present-day continents. A timely problem in modern paleogeographic investigations is the use of the general picture described above for an explanation and detailed description of Mesozoic-Cenozoic climates. Scientific expositions of this type can be found in the materials of international conferences on problems in paleoclimatology which have been held during recent years (Newcastle, 1963; Norwich, 1975, and others), and also in the works of individual scientists, such as the investigations of H. H. Lamb (1977) and H. Flohn (1969) and others.

Interesting theoretical principles for paleoclimatic studies of this sort were proposed by M. I. Budyko (1971, 1974). They involved a recognition, as the most important climate-forming factor in the earth's geological past, of the energy balances of the atmosphere and hydrosphere, in which an important role is played by heat transfer between the poles and the equator, effectuated by ocean currents. Since, according to the historical geology model cited above, in the course of a considerable part of the Mesozoic-Cenozoic there was an extensive world ocean, or in any case, there was free communication between its polar and equatorial parts, extensive meridional heat transfers should then play a greater role in comparison with the present epoch. This factor explains well the predominance of hot climates in these geological epochs and also the development of primarily concentric climatic zones on the continents with different moistening levels.

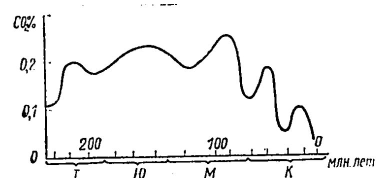

Fig. 1. Evolution of gas composition of the atmosphere (according to M. I. Budyko).

The reasons for the cyclic changes in the climates of the Mesozoic and Cenozoic and their different amplitude could be different phenomena. However, in the latest studies particularly great attention is being devoted to a periodic change in the gas composition of the atmosphere, and in particular, to variations in its CO_2 content. Among the many investigations of this kind we must mention the studies of M. I. Budyko, who, using data from historical geology, constructed a well-known curve of the geological evolution of atmospheric gas composition for 200 million years (Fig. 1). According to this curve, with a general tendency to a decrease in CO_2 content during the course of the Mesozoic-Cenozoic there were repeated waves of its increase and decrease. Without touching here on the reasons for this global phenomenon (M. I. Budyko attributes it, for the most part, to the cycles of volcanic activity), we recall that most modern investigations relate the so-called "greenhouse" effect in change in the structure of the atmospheric radiation balance to periods of increased CO_2 content in the earth's atmosphere and as a result, epochs of considerable, anomalous warming coincide with this phenomenon. Sensational paleoclimatic conclusions are drawn on this basis.

A specific example of such conclusions is found in an article by D. I. Macklin entitled "Greenhouse at the End of the Mesozoic; Lessons of the Past," published in SCIENCE during the past year. The article is devoted to an examination of the so-called "time of the great dying out," the mass disappearance on the earth of many representatives of Mesozoic fauna at the end of that era and on the boundary with the Cenozoic, that is, about 120-150 million years ago.

The author of the above-mentioned article, making extensive use of data from the latest investigations of many scientists, convincingly demonstrates that the main reason for this global biological catastrophe (ecological crisis) was the sudden and rapid warming of general climate, caused by a marked increase in the CO_2 concentration in the atmosphere, resulting in a strong "greenhouse" effect. Relying on investigations demonstrating the increasing anthropogenic concentration of CO_2 in the modern atmosphere, he predicts a new ecological catastrophe for life on earth similar to that occurring in the Mesozoic-Cenozoic.

In this article there is no possibility for a thorough discussion of the Mesozoic-Cenozoic ecological catastrophe. The fact that this geological period was characterized by very great paleogeographic changes is evidently unquestionable. It is sufficient to mention that the beginning of the breakdown of the unified land mass (Pangeia) dates back precisely to that period of time, as does the development of oceanic spreading and subduction, the onset of the Laramie-Alpine orogenesis, etc. Moreover, the M. I. Budyko curve shown in Fig. 1, representing the evolution of atmospheric composition in the geological past, much like the similar curve in the report by Professor B. Bolin, presented at the World Climate Conference (Geneva, 1979), predicting an anthropogenic effect from the combustion of fuels, accordingly indicates both the past and also possibly the future of a high "wave" in the increase in the concentration of atmospheric CO_2 and the possible appearance of a strong "greenhouse" effect.

Nevertheless, such a simple analogy between the geological past and the future, identification of the Mesozoic-Cenozoic "greenhouse" with a postulated "greenhouse effect" of anthropogenic origin, in our opinion is unjustifiable. Even if we do not touch upon the purely biological aspects of the Mesozoic-Cenozoic ecological crisis, general paleogeographic arguments speak against such an analogy. Thus, for example, in order to duplicate such a biological "catastrophe" it is necessary that the entire present-day face of the earth be subjected to a rapid and fundamental regeneration. In place of the rich and diversified modern nature with many reliable ecological "niches" -- refuges from all possible climatic misfortunes, our earth must again be transformed into a uniform unified land mass deprived of natural refuges, a Pangeia washed by an extensive and also a unified world ocean. But the course of geological evolution is irreversible.

Now we will turn to later stages in the geological history of the earth.

It is generally recognized that during the course of the Cenozoic there was development of a general global cooling, an increase in the contrast of seasons of the year and complication of natural climatic zonality.

Such a transition is well documented by paleoclimatic reconstructions for the Miocene and Pleistocene. M. I. Budyko (1971) attributes this to the fact that during the course of the Tertiary there was gradual development of isolation of the polar basin (in the northern hemisphere) from the tropical regions of the ocean, which caused a decrease in temperature at the pole and approach of the distrubtion of radiation heat to the values characteristic for the Quaternary.

Paleogeographic data on climatic changes in the Tertiary can and must be used for prognostic purposes. In this connection particular attention must be given to the preglacial period, that is, that period in the paleogeographic evolution of the earth during which the climate-forming factors, determining the onset of the glacial period, still had not appeared, although the geographic positioning of the continents and oceans was close to that of the present day. In the classical summary of M. Schwarzbach (1956) the climate of this time was characterized as follows: "In general the climate of the Pliocene was rather similar to that of the present day, although it was somewhat warmer" (p 197). In another classical summary by C. Brooks it is asserted that "the climatic zones in Europe (in the Miocene-Pliocene) were displaced by 10 or 15° to the north in comparison with their present-day positioning" (p 12). Finally, in the up-to-date summary of H. H. Lamb (1977) the author gives generalized data on paleotemperatures in the southern hemisphere and demonstrated how the tropical conditions here are replaced by subtropical and temperate conditions. Generalizations of all data of this kind make possible their quite valid use for prognostic purposes.

In a report by H. Flohn at the World Climate Conference (Geneva, 1979) very great prognostic significance is given precisely to this geological period. He called it the period of "an ice-free Arctic and a glaciated Antarctic continent." Its age was determined as: from 12 to 2.5 million years ago. A very interesting theme for scientific discussion would be a discussion of that hypothetical model of the paleogeography of this period which is set forth in the report by Professor H. Flohn. As follows from the text of the report, the anthropogenic increase in the CO_2 concentration can, as visualized by the speaker, lead in the immediate future to a "reproduction" of the paleogeography of precisely this period.

It is important to note that the latest archeological finds of ancient man (to be more precise, pre-man), encountered in East Africa, are related to precisely this time (its upper limit). The phylogeny of the human species, as is well known, is rather complex and extends over the last several million years.

The problem of the role of the environment in the appearance of ancient man is very interesting and there is still much which is unclear. The region of the rift valleys of East Africa, where the remains of the most ancient man were recently found, judging from paleobiological data, was characterized by a rather diversified wooded savanna landscape. It was postulated that a highly important role in the transition from primates to pre-man was played by an omnivorous life, high mobility and the possibility of active attack and defense, which freed him from the ecological "niche" of the primates and made it possible to exist in different natural ecosystems already existing in this region. However, this was nevertheless only relative natural independence.

As is well known, the principal pattern in the paleogeography of the Pleistocene (from two million years ago to the present time) was major cycles in glacial and interglacial epochs (Table 3), marked by periodic spreading of extensive glacial covers over the continents and in the polar region during glacial epochs and a marked reduction of these covers to their present extent and smaller in the interglacial epochs. The advances and retreats of the glacial covers were accompanied by major eustatic variations in the level of the world ocean: its decrease by many tens of meters in epochs of glaciations and an increase in the interglacial epochs. It is almost universally recognized that such cycles of ancient glaciations were caused by periodic changes in the quantity of incident radiation (M. Milankovich, 1930; R. F. Flint, 1947; I. P. Gerasimov, K. K. Markov, 1939; F. Zeuner, 1959, and others). It is assumed that in the low latitudes there were similar cycles of pluvial and xerothermic epochs. As indicated by modern investigations, paleogeographic changes played an important role in the evolutionary development of man and the progress of material culture of primitive society. During the time of these changes there was an anthropological differentiation of humanoids with the formation of blind alleys in man's development (Neanderthal man). Climatic changes in the course of the Pleistocene were evidently the reason for the first ecological crises in the history of human society and exerted an influence on his general progress and his smooth transition from a life as a gatherer to a life as a hunter, the development of agriculture and the raising of livestock (Table 4). And although with the passage of time, with the development of material culture and the social structure of society, the dependence of human activity on climate weakened and was modified, at the present time, at a very high stage in development, we must again return to this subject.

All the principal geological events of the Pleistocene, and in particular, their paleoclimatic causes and effects, have been discussed at many recent international scientific congresses, conferences and symposia, whose materials have been regularly published. Among these we will mention the congresses of the International Association for Study of the Quaternary, held in Paris (1969), Christchurch (1973), London (1977); International Symposium on Quantitative Methods for Determining Climatic Changes During the Pleistocene (Giv-sur-Ivette, 1973); International Symposium on Long-Term Climatic Variations (Norwich, 1975); Soviet-American symposia on paleoclimology of the Quaternary and others. The results of the latest investigations of these matters in the works of S. Emiliani, N. A. Morner, C. Charles, I. Fink, H. Flohn, A. A. Velichko, and others are of great interest.

In this report we are unable to present a systematic examination of the entire problem of Pleistocene paleoclimate. There is probably no need of this because the most important problem in present-day paleoclimatology is the defining of the principal time boundaries, similar to the "preglacial epoch" (Miocene-Pliocene) capable of having prognostic importance. In our opinion, such principal boundaries in the course of the Pleistocene can be considered, first of all, the last warm interglacial period (Riss-Würm, Eem, Sangamon), and second, the coldest stage of the last glaciation (late Würm, Valday, Wisconsin).

The last warm interglacial period, occurring 120-75 thousand years ago, was well expressed on a global scale. In the monograph PALEOGEOGRAFIYA YEVROPY V POZDNEM PLEYSTOTSENE (Paleogeography of Europe in the Late Pleistocene) (Moscow, 1978), in special maps (Fig. 2), there is a generalization of the corresponding paleogeographic data. According to these data, the continental ice was completely absent over the territory of Europe during the course of the last interglacial period; almost the entire continent was occupied by woody vegetation; the boundary of broadleaf forests ran 5-6° to the north of its present position, there was no tundra and the boundary of the steppes was also greatly displaced toward southeast Europe.

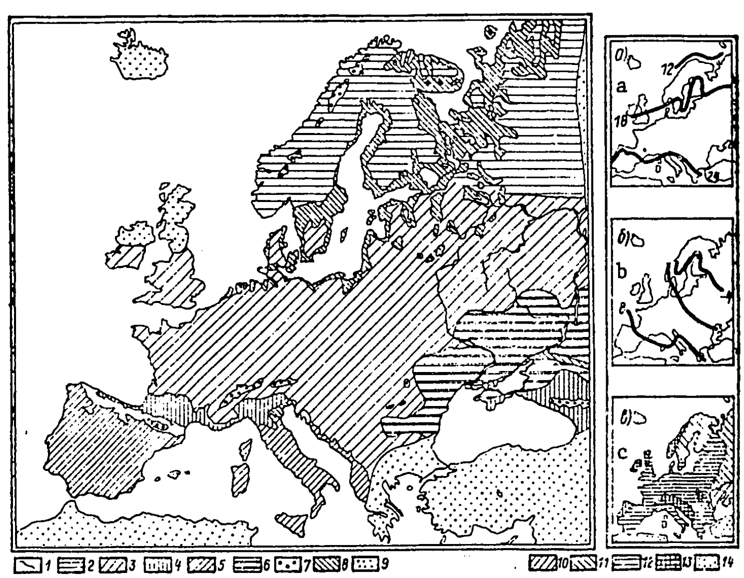

Fig. 2. Nature of Europe in the epoch of the last interglacial period (from V. P. Grichuk) and its climatic characteristics (from A. A. Velichko and V. A. Klimanov). a) mean July temperature; b) mean January temperature; c) precipitation (mm). 1) shoreline; 2) boreal (taiga) forest; 3) Atlantic forests; 4) subtropical (Mediterranean) humid forests; 5) subtropical (Mediterranean) arid forests, 6) steppe; 7) high-mountain forest and meadow; 8) no reconstruction; 9) inundated areas; 10) 400-600; 11) 500-700; 12) 700-1,000; 13) > 1,000; 14) no reconstruction

Table 1

Table of Geographic Zonality (from M. I. Budyko, 1977)

Тепловая энергетическая база — радиационный баланс 1	3 Условия увлажнения — радиационный индекс сухости								
	<0 (крайне избыточное увлажнение) 2	0—1 (избыточное увлажнение) 4				5 оптимальное увлажнение	6 1—2 (умеренно недостаточное увлажнение)	7 2—3 (недостаточное увлажнение)	>3 8 (крайне недостаточное увлажнение)
		0—1/5	1/5—2/5	2/5—3/5	3/5—4/5	4/5—1			
9 <0 (высокие широты)	I Вечный снег	—	—	—	—	—	—	—	—
10 0—50 *ккал/см²* в год (южноарктические, субарктические и средние широты)	13 —	IIа 14 Арктическая пустыня 14	IIб 15 Тундра (на юге с островками редколесий), заболоченное мелколесье	IIв 16 Северная и средняя тайга	IIг 17 Южная тайга и смешанные леса	IIд 18 Лиственный лес и лесостепь	III 19 Степь	IV 20 Полупустыня умеренного пояса	V 21 Пустыня умеренного пояса
11 50—75 *ккал/см²* в год (субтропические широты)	—	—	22 VIа Районы субтропической гемигилеи со значительным количеством болот	23 VIб Дождевые субтропические леса			24 VII Жестколиственные субтропические леса и кустарники, листопадные леса	25 VIII Субтропическая полупустыня	26 IX Субтропическая пустыня
12 >75 *ккал/см²* (тропические широты)	—	—	27 Xа Районы преобладания экваториальных лесных болот	28 Xб Сильно переувлажненный (сильно забол.) экваториальный лес	29 Xв Среднепереувлажненный (средне забол.) экваториальный лес	30 Xг Экваториальный лес, переходящ. в светлые тропические леса и лесные саванны	31 XI Сухая саванна, листопадные леса	32 XII Опустыненная саванна (тропическая полупустыня)	[illegible] Пустыня тропическая

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KEY TO TABLE 1

1. Thermal energy base-radiation base
2. (extremely excessive moistening)
3. Moistening conditions-dryness radiation index
4. (excess moistening)
5. optimum moistening
6. (moderately inadequate moistening)
7. (inadequate moistening)
8. (extremely inadequate moistening)
9. high latitudes
10. 0-50 Cal/cm^2 per year (south arctic, subarctic and middle latitudes)
11. 50-75 Cal/cm^2 per year (subtropical latitudes)
12. $>$ 75 Cal/cm^2 (tropical latitudes)
13. Eternal snow
14. Arctic desert
15. Tundra (in south with patches of scattered forest), swampy areas with low trees
16. Northern and middle taiga
17. Southern taiga and mixed forests
18. Hardwood forest and wooded steppe
19. Steppe
20. Semideserts of temperate zone
21. Deserts of temperate zone
22. Regions of subtropical savanna with considerable number of swamps
23. Rainy subtropical forests
24. Hard-leaf subtropical forests and scrub, deciduous forests
25. Subtropical semidesert
26. Subtropical desert
27. Regions of predominance of equatorial wooded swamps
28. Highly overmoistened (very swampy) equatorial forest
29. Moderately overmoistened (moderately swampy) equatorial forest
30. Equatorial forest, with transition into light tropical forests and wooded savanna
31. Dry savanna, deciduous forests
32. Savanna with transition to desert (tropical semidesert)
33. Tropical desert

Table 2

Climatic Characteristics of Present-Day Natural Formations

	Главные типы 1	Климат 2	Температура, °С 3		Атмосферные осадки, мм/год 6
			зима 4	лето 5	
7 Коры выветривания и континентальные отложения	Сиаллитные глеевые 10	Холодный умеренно-влажный 25	—10 и ниже 36	10 и ниже	<250
	Сиаллитные 11	Умеренно-холодный; умеренно-влажный 26	0 и ниже 36	10—20	250—500
	Сиаллитные карбонатные (лессы и др.) 12	Теплый; сухой 27	0—10	20—30	100—250
	Ферраллитные (латеритные коры и др.) 13	Жаркий; переменно-сухой 28	10—20 и выше 37	30 и выше	<500
	Аллитные (каолины, бокситы и др.) 14	Жаркий влажный 29	10—20 и выше 37	30 и выше	<500
8 Почвы	Тундровые глеевые 15	Холодный; умеренно-влажный 30	—20 и ниже	10 и ниже	<250
	Таежные подзолистые 16	Умеренно-холодный; умеренно-влажный 31	—10 и ниже 36	10—20	<500
	Степные (черноземы и др.) 17	Теплый; умеренно-сухой 32	0—10	20—30	<500
	Пустынные (сероземы и др.) 18	Теплый; сухой 27	>0	30—40	<250
	Субтропические (красноземы и др.) 19	Теплый, переменно-влажный 33	0—10	30—40	<1000
	Тропические сухие (красноземы и др.) 20	Жаркий; сухой 34	10—20	30—40	<1000
	Тропические влажные (латеритные и др.) 21	Жаркий, влажный 29	>20	30—40	>1000
	Лесные бурые 22	Теплый, умеренно-влажный 35	0—10	20—30	<1000
9 Криогенные образования	Вечная мерзлота 23	Холодный; умеренно-влажный 30	—20 36	20	<500
	Современные ледниковые покровы 24	Холодный; сухой 34	—30 и ниже	<0	<250

38 Примечание. Климатические показатели вычислены по картам Физико-географического атласа мира (Москва, 1964)

KEY TO TABLE 2

1. Chief types
2. Climate
3. Temperature, °C
4. Winter
5. Summer
6. Atmospheric precipitation, mm/year
7. Weathered crusts and continental deposits
8. Soils
9. Cryogenic formations
10. Siallitic gleyey
11. Siallitic
12. Siallitic calcareous (loesses, etc.)
13. Ferralitic (lateritic crusts, etc.)
14. Allitic (kaolins, bauxites, etc.)
15. Tundra gleyey
16. Tundra podzolic
17. Steppe (chernozems, etc.)
18. Desert (gray soils, etc.)
19. Subtropical (red soils, etc.)
20. Tropical dry (red soils, etc.)
21. Tropical moist (lateritic soils, etc.)
22. Brown forest soils
23. Permafrost
24. Present-day glacial covers
25. Cold moderately moist
26. Moderately cold; moderately moist
27. Warm; dry
28. Hot; variably dry
29. Hot moist
30. Cold; moderately moist
31. Moderately cold; moderately moist
32. Warm; moderately dry
33. Warm, variably moist
34. Hot; dry
35. Warm; moderately moist
36. and lower
37. and above
38. Note. Climatic indices computed using maps from the PHYSICAL GEOGRAPHY ATLAS OF THE WORLD (Moscow, 1964)

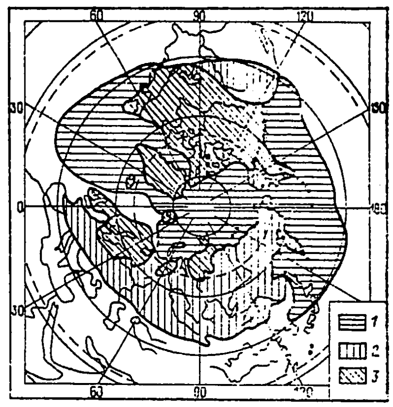

Fig. 3. Cryogenic region of northern hemisphere in third stage of Pleistocene. 1) sea glaciation, 2) permafrost, 3) continental glaciation

All our data, taken together, give a basis for assuming that the climatic conditions of the last interglacial period had an intermediary character between the preglacial (Miocene-Pliocene) period considered above and the present time. In other words, climate was cooler in comparison with the preglacial period, but warmer in comparison with the present day. The general character of natural zonality in Europe gives basis for assuming a considerable eastward advance (in comparison with the present day) of the region of marine climate.

According to all the available paleogeographic data, the coldest stage during the entire Pleistocene was the last phase of the last glaciation, occupying the time period from 20-25 to 10-12 thousand years. A. A. Velichko (1973) called this age boundary the third cryogenic stage of the Pleistocene, which replaced the preceding stage -- the glaciogenic stage. By these definitions it was emphasized that in the late phase of the last glaciation the propagation of continental and sea ice was not maximum, in contrast to the occurrence of permafrost, at that time advancing far beyond the limits of the glacial formations. Figure 3 shows this important pattern. The same is indicated by Fig. 4, in which the reconstruction of the nature of Europe at that time is represented. As this map shows, the general character of the plant cover at the considered time was very specific and did not have analogues in the present-day vegetation of Europe. Periglacial birch and leafy, grassy thin wooded areas extended along the margin of the Scandinavian glacial shield. In the west this zone merged with zones of tundras and subarctic meadows, whereas to the south it underwent transition into a broad zone of periglacial cold steppe. This entire zone was marked with traces of former development of permafrost with a mean annual temperature to -5°C and a thickness 100-150 m. The only apparent present-day analogue of these landscapes is regions of Central Yakutia, situated near the cold pole of Eurasia. Table 5 also gives such a comparison.

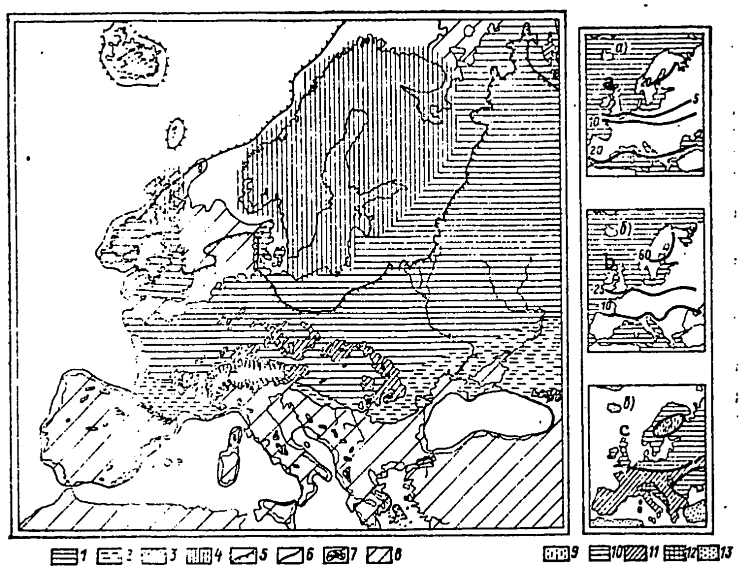

Fig. 4. Last glaciation of Europe, its periglacial period (according to A. A. Velichko, V. V. Berdnikov, V. P. Nechayev, 1978) and climatic characteristics of Europe (according to A. A. Velichko and V. A. Klimanov). a) mean July temperature; b) mean January temperature; c) precipitation (mm). 1) development of continuous permafrost (lowland periglacial); 2) development of "island" permafrost; 3) mountain periglacial; 4) glacier cover; 5) boundary of maximum glaciation; 6) shoreline; 7) mountain glaciation; 8) no reconstruction; 9) < 200; 10) 200-300; 11) 300-400; 12) > 400; 13) no reconstruction

It should be noted that paleoclimatic investigations undertaken by American specialists under the CLIMAP program gave results for the considered time limits (15-20 thousand years ago) which are entirely similar to those presented above. These results pertain to the North Atlantic and are based primarily on paleotemperature data. These are represented in Fig. 5, which shows the distribution of the temperature deviation of surface waters of the ocean from present temperatures. During the period of the Late Würm these deviations attained an enormous value of -10 C.

Proceeding on the basis of traditional concepts concerning the appearance and stable state of an anticyclonic climatic regime over extensive glacial areas and the "thoroughly frozen" areas adjacent to them, it must be assumed that the paleoclimatic conditions of the coldest phase of the Pleistocene were sharply different from today. The hypotheses of a marked restructuring of the entire system of oceanic and atmospheric circulation, occurring during the considered time interval, are entirely probable. A. A. Velichko calls such a restructuring "hyperzonal" and emphasizes a strong weakening of latitudinal atmospheric circulation at that time and an intensification of meridional circulation (in contrast to the interglacial period).

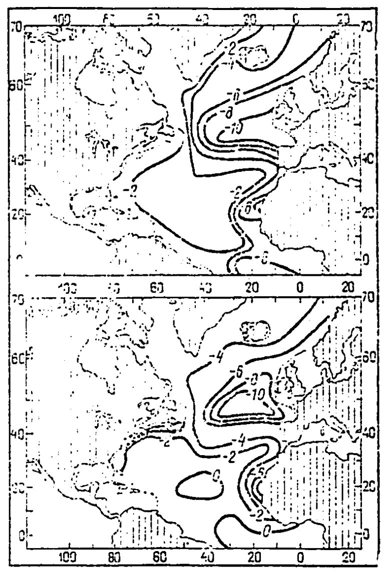

Fig. 5. Prevailing temperatures of the sea surface during the last glaciation maximum about 15-17 thousand years ago as the deviation (°C) from the present-day level. a) winter; b) summer

After the epoch of maximum cooling (25-12 thousand years ago) and the gradual degradation of the last glacial covers in the course of the Holocene there was a successive change in the climatic phases of the post-glacial period in accordance with the Blytt-Sernander scheme, for the first time finding global application (Table 6). According to this scheme, during the post-glacial period over the course of 11-12 thousand years there was one general epoch of maximum warming (Atlantic time -- 5-8 thousand years ago), which was interrupted and ended with colder epochs (boreal, subaerial times).

Already rather long ago it was postulated that there is a possible analogy between the post-glacial (Holocene) period, beginning 11-12 thousand years ago, and the interglacial periods. It followed from this hypothesis that similar to an interglacial period, the Holocene is characterized by a definite cycle of climatic changes from the initial cooling to the climatic optimum (about 5 thousand years ago), and then to a new cooling -- a precursor of a new glaciation.

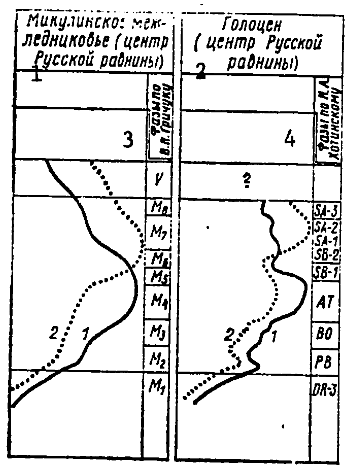

Fig. 6. Diagram of comparison of climatic and phytocenological stages of the Pleistocene rhythm, Mikulin interglacial period and Holocene. 1) temperature; 2) moistening; M_1 -- periglacial complex; M_2 -- birch-pine forests; M_3 -- same, with admixture of broad-leaf species; M_4 -- broadleaf forests of oak and elm; M_5 -- same with linden maximum; M_6 -- same with hornbeam maximum; M_7 -- fir forests; M_8 -- pine forests with fir and birch; V -- birch forests with elements of tundra flora; DR-3 -- periglacial complex; PB -- birch-pine forests; BO -- same with admixture of broadleaf species; AT -- broadleaf forests of oak, elm and linden; SB-1 -- birch-pine forests; SB-2, SA-1, SA-2 -- fir forests; SA-3 -- birch-pine forests

KEY:

1. Mikulin interglacial period (center of Russian Plain)
2. Holocene (center of Russian Plain)
3. Phases according to V. P. Grichuk
4. Phases according to N. A. Khotinskiy

In Fig. 6 this representation is checked (for the center of the Russian Plain) primarily on the basis of paleobotanical data. This figure gives a comparison of the course of climatic changes in the course of the last interglacial period and the Holocene. The result of the comparison gives basis for assuming that the historical period and the modern period can be regarded as a transition from the post-glacial climatic optimum (Atlantic phase) to a colder climatic level, preceding the onset of a new glaciation. This transition, to be sure, is not gradual; it is complicated by periodic epochs of warming and cooling (similar to the so-called "small glacial period"). However, a general tendency to progressive cooling clearly follows from paleogeographic data.

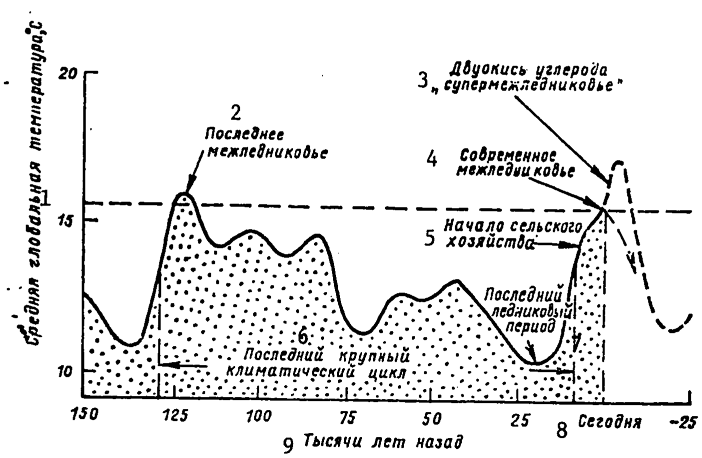

Fig. 7. Geological history of the past and prediction of future climate. In accordance with the version of the astronomical theory of glacial periods proposed by Hayes, et al., receiving further development in quantitative expression in the studies of John Imbrey and John Z. Imbrey (1978), the natural course of future climate (represented by a dashed curve) will be expressed in a tendency to cooling which will lead to glacial conditions after 23 thousand years. However, the warming effect of carbon dioxide can lead to the appearance, in the course of natural events, to a "superinterglacial" period when mean global temperatures will be several degrees higher than in any other period in the course of the last million years. In this case the onset of a tendency to cooling, leading to the next glacial period, will be delayed until the warming truly stops; this will possibly occur after 2 thousand years from the present time (according to Mitchell, 1977, Imbrey and Z. Imbrey, 1978).

KEY:

1. Mean global temperature
2. Last interglacial period
3. Carbon dioxide "superinterglacial" period
4. Present-day interglacial period
5. Beginning of agriculture
6. Last major climatic cycle
7. Last glacial period
8. Today
9. Thousands of years ago

On the basis of these data it is possible to make rough calculations of the rate of development of cooling. These show that clear evidences of the onset of a new glacial epoch can appear in the course of the next thousand years.

Table 3

Scheme of Breakdown of Pleistocene

Подразделения 1	Абсолютный возраст, тыс. лет 2	Альпы 3	Западная Европа 4	Восточная Европа 5	Северная Америка 6
7 Верхний	50 100	10 **Вюрм** 11 Рисс—Вюрм	17 **Вислинское** 18 Эем	23 **Валдайское** 24 Микулино	29 **Висконсин** 30 Сангамон
8 Средний	200 300 400	12 **Рисс** 13 Миндель—Рисс	19 **Заальское** 20 Гольштейн	25 **Московское** 26 Одинцово 27 **Днепровское** 28 Лихвино	31 **Иллинойское** 32 Ярмут
9 Нижний	500 600 700 800 1000	14 **Миндель** 15 Гюнц—Миндель 16 **Гюнц**	21 **Эльстерское** 22 Кромер		33 **Канзасское** 34 Афтон 35 **Небрасское**

36 Примечание. Жирным шрифтом выделены названия ледниковых эпох

KEY:
1. Subdivision
2. Absolute age, thousands of years
3. Alps
4. Western Europe
5. Eastern Europe
6. North America
7. Upper
8. Middle
9. Lower
10. Würm
11. Riss-Würm
12. Riss
13. Mindel-Riss
14. Mindel
15. Günz-Mindel
16. Günz
17. Visla
18. Eem
19. Saal
20. Holstein
21. Elster
22. Cromer
23. Valday
24. Mikulino
25. Moscow
26. Odintsovo
27. Dnepr
28. Likhvino
29. Wisconsin
30. Sangamon
31. Illinoisan
32. Yarmouth
33. Kansan
34. Aftonian
35. Nebraskan
36. Note. The underlining corresponds to the names of the glacial epochs

However, there is no basis for ending this article with such a pessimistic forecast. Even if we assume the above-mentioned natural trend to be well-reasoned, nevertheless we cannot be guided by it in a general forecast. Undoubtedly, modern climatic change will more and more be determined by anthropogenic influences on climate-forming factors. An examination of such effects, the degree of their intensity and time parameters is beyond the limits of this article. However, it is clear that both the present-day, and especially the future activity of human society is undoubtedly capable not only of "overcoming," but even "turning around" the natural trends in the geological evolution of climate. In other words, it can create the prerequisites for the appearance of those climatic situations on local, regional and global scales which can, despite the natural course of events, be similar to different paleoclimatic scenarios.

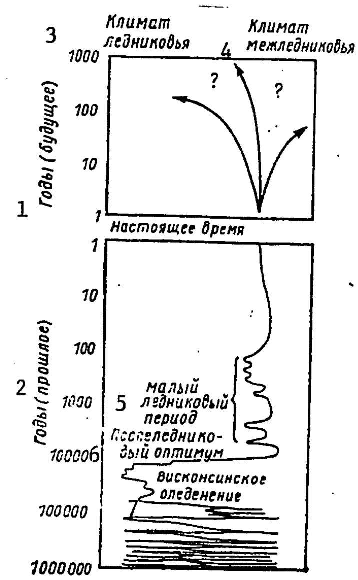

Fig. 8. Climatic changes during the last million years and possible short-range climatic tendencies in the future.

KEY:

1. Years (future)
2. Years (past)
3. Glacial climate
4. Interglacial climate
5. Small glacial period
6. Post-glacial optimum
7. Wisconsin glaciation

Paleoclimatology can propose that mankind make a choice from a whole series of climates of past geological epochs. The most possible of them are three variants suggested by geological history: very warm and moist, but rather uniform over great areas, a preglacial (Miocene-Pliocene) period, less warm, but with considerable spatial variations, an interglacial climate, and finally, an intermediate climate (from interglacial to modern) of an epoch of a post-glacial climatic optimum.

Table 4

Абсолютный возраст, тыс. лет 1	Человек 2	Материальная культура 3	Природа 4
		Верхний палеолит 9	Вюрм 12
100	Неантропы (неандертальцы) 5	Средний и нижний палеолит 10	Рисс—Вюрм 13 Рисс
350	Палеантропы (питекантропы) 6		Миндель—Рисс 14 Миндель
700	Архантропы 7	Эопалеолит (культуры галек и чоплеров) 11	Гюнц—Миндель 15 Гюнц
1500	Австралопитеки 8		

KEY:
1. Absolute age, thousands of years
2. Man
3. Material culture
4. Nature
5. Neanthropic (Neanderthal man)
6. Paleoanthropic (Pithecanthropus)
7. Archanthropic
8. Australopithecus
9. Upper Paleolithic
10. Middle and Lower Paleolithic
11. Eopaleolithic
12. Würm
13. Riss-Würm
14. Riss
15. Mindel-Riss
16. Mindel
17. Günz-Mindel
18. Günz

Table 5

Время 1	Температура, °С 2			Атмосферные осадки, мм/год 6
	января 3	июля 4	средние годов. 5	
7 Современность (г. Брянск)	—8,5	18,4	10	580
8 Максимум похолодания (поздний валдай)	—40÷—45	16—18	—10÷—12	100—150
9 Максимум потепления (микулинское межледниковье)	~0	18	9—10	600—700
10 Современность (г. Якутск)	—43,2	18,7		

KEY:
1. Time
2. Temperature, °C
3. January
4. July
5. Mean annual
6. Precipitation, mm/year
7. Present time (Bryansk)
8. Cooling maximum (Late Valday)
9. Warming maximum (Mikulin interglacial)
10. Present time (Yakutsk)

Table 6

Periods of Holocene (Blytt-Sernander Scheme)

Индексы 1	Абсолютная датировка 2	Периоды 3	Климат 4
ДР	12000 11000 5	Арктический и субарктический (поздний дриас, аллеред)	11 Холодный
PB BO	8000 6 7	Предбореальный Бореальный	12 Вначале прохладный и сухой, затем умеренно теплый
AT	5000 8	Атлантический	13 Теплый и влажный
B_{1-3}	2000 9	Суббореальный с подразделениями	14 Теплый и сухой
A_{1-3}	10	Субатлантический с подразделениями	15 Прохладный и влажный

KEY:
1. Indices
2. Absolute dating
3. Periods
4. Climate
5. Arctic and subarctic (Late Drias, Allered)
6. Preboreal
7. Boreal
8. Atlantic
9. Subboreal with subdivisions
10. Sub-Atlantic with subdivisions
11. Cold
12. Initially cool and dry, then moderately warm
13. Warm and moist
14. Warm and dry
15. Cool and moist

Many investigators of anthropogenic climatic changes feel that under the influence of an increase in the concentration of carbon dioxide and other factors in the next few decades there will be an increasing change in climate in the direction of a warming. If this process occurs calmly, the climatic conditions of the last interglacial period can be rapidly overshadowed by the formation of a "superinterglacial" period (Fig. 7). However, if such a process of anthropogenic warming of climate is monitored and becomes controllable, the best model can be an analogue of a "preglacial" period (the right arrow in Fig. 8), with which, however, models of a warm interglacial period or a post-glacial climatic optimum can compete.

The hope must be expressed that even before the appearance of a radical change in global climate under the influence of economic activity ways will be found to modify climates, making it possible to prevent undesirable changes in man's environment and to ensure the entire earth stable optimum climatic conditions.

In conclusion we will express several hypotheses concerning the principal objectives of further paleoclimatic investigations. They are:

1. It is necessary to have a universal broadening of paleoclimatic (paleogeographic) investigations as a basis for prognostic climatic studies. Together with a thorough study of traditional objects (geological deposits and paleobiological remains) particular attention must be devoted to an investigation of thick strata of ancient continental ice, cave formations with archeological remains, bottom deposits of major lakes and abyssal ocean sediments. When carrying out these investigations it is necessary to ensure the close cooperation of professional paleogeographers and paleobiologists.

2. There must be further development of present-day geomorphological, geochemical, lithological and biological research methods, and among them, in particular, isotopic methods for determining absolute age and geochemical methods for determining the characteristics of environmental conditions (for example, temperature, salinity, gas composition, etc.) and paleoecological peculiarities of organisms.

3. Attention must be concentrated on five time intervals having fundamental prognostic importance: preglacial (12-2.5 million years), last interglacial period (50-100 thousand years), last glaciation (18-20 thousand years), climatic optimum of the post-glacial period (5-8 thousand years), and the so-called "small glacial epoch" (1500-1800 A.D.).

4. As the fundamental method for the generalization of regional data it is necessary to make extensive use of paleogeographic reconstructions in the form of maps and atlases for large regions of the land and ocean with their maximum saturation with quantitative characteristics. On the basis of international scientific cooperation it is necessary to organize a generalization of these regional materials for the northern and southern hemispheres and the entire earth, in particular, for the main prognostic time periods (see above).

5. On the basis of paleogeographic maps and atlases and the general theory of climate it is necessary formulate conceptual and quantitative models of former climates and climate-forming processes as probabilistic prognostic models.

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MONITORING OF CLIMATE AND THE SERVICE FOR COLLECTING CLIMATIC DATA NECESSARY FOR DETERMINING CLIMATIC CHANGES AND FLUCTUATIONS. MONITORING OF DATA RELATED TO CLIMATE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 54-67

[Article by Corresponding Member USSR Academy of Sciences Yu. A. Izrael', USSR State Committee on Hydrometeorology and Environmental Monitoring, submitted for publication 13 March 1979]

Abstract: The author has formulated the purposes and problems of climatic monitoring. The article defines the requirements on the accuracy of measurements and the principles for determining the priority for obtaining the data used in man's economic activity and for understanding climatic changes. The role of satellites in the monitoring of climate is specially discussed. [This is the basic content of a report at the World Climate Conference (Geneva, 12-23 February 1979).]

[Text] 1. Introduction. The organization of climatic monitoring and a service for the collection of climatic data is a necessary link in the study of climate, its possible changes and variations, practical use of information on climate for managing and developing the economy, and optimization of the relationships between human society and nature. The World Meteorological Organization (WMO) and many national meteorological services have already for a long time been collecting such data and favoring their use in man's practical activity. The first problem in the planned World Climatic Program is climatic monitoring and the representation of climatic data [9]. This direction is also highly important in the Soviet comprehensive program for investigating the earth's climate.

By the term "environmental monitoring" is meant a purposeful program of observations of the state of the environment. In many cases the term "monitoring" is applied to an observation system making it possible to discriminate changes in the state of the biosphere under the influence of anthropogenic activity [4]. Monitoring, according to such a definition, includes observations, evaluation and prediction of anthropogenic changes, clarification of the sources of effects and the reasons for these changes. It is also possible to use the term "climatic monitoring" in such an understanding.

If climate is regarded as an atmospheric phenomenon, it can be described by a set of statistical characteristics of possible states of the atmosphere. However, for an understanding of climatic changes and fluctuations it is insufficient to have only atmospheric data; it is necessary to have information on the state of the climatic system "atmosphere-ocean-cryosphere-land surface (with rivers and lakes)-biote," on the state and interaction of elements of this system. It is obvious that for discriminating anthropogenic climatic changes and fluctuations it is necessary to make a careful study of the natural variability of climate.

2. Place of Monitoring and the Service for Collecting Climatic Data in Scientific Investigations and Solution of Practical Problems

A reliable description and evaluation of modern climate, prediction of its possible changes and fluctuations require a great amount of data and the objective is a thorough analysis of the state of the environment and the modeling of climate [15].

The solution of a great many practical, applied problems in agriculture, power production, construction and other types of economic activity of man require extensive climatic information. For these purposes the service for the collection of climatic data seems necessary and evidently has the highest priority.

An extensive mass of data on individual characteristics of elements of the biosphere and on the processes determining climatic variability is necessary for the study of climatic changes and fluctuations and for an understanding of such changes. This applies, in particular, to study of the natural spatial-temporal variability of climate on different scales.

The prediction of seasonal and year-to-year fluctuations of climate requires the organization of a special global observation system, in general nonuniform in space and in time. In order to organize such a system it is important to define the zones on the earth and in the world ocean which exert the greatest influence on such fluctuations. For example, as demonstrated by Academician Marchuk [13], the weather in a number of regions of the northern hemisphere is substantially determined by the state of the ocean and its interaction with the atmosphere in the equatorial part of the Atlantic Ocean and some regions of the Pacific Ocean. Observations directed to s study of variability must take into account the inertia of the climatic system.

The organization of the collection of data on climates of the past can also be regarded as "monitoring" -- for this purpose it is necessary to create a system for the collection and study of fossil and other indirect data on possible climatic fluctuations and changes during recent centuries, millenia and more remote time intervals. An analysis of such data makes it possible to study the influence of changes in the climatic system on climate in the past.

The possibility of anthropogenic climatic changes requires a study of the influence of changes in the characteristics of the underlying surface (as a result of construction of major hydraulic structures, changes in the area of forest plantings and other effects) on climate, study of the anthropogenic changes in the composition and optical properties of the atmosphere (as a result of the ejection of aerosol particles and different gaseous impurities and also the possible influence of heat escape). An evaluation of global atmospheric contamination and its influence on climate is recognized by UNEP as one of the goals of the global system for monitoring of the environment [7].

In turn, natural and anthropogenic climatic changes can exert an influence on the state of the biosphere, causing different ecological consequences. They can also exert a substantial influence on the economic activity of man, and in the long run, on the health and well-being of man. This aspect of the investigations is of enormous practical importance and requires the organization of an observation system; study of the effect on ecological systems in different regions evidently will require comprehensive observations in zones undisturbed by local anthropogenic activity -- zones of biospheric reserves.

3. Principal Goals and Problems

Thus, climatic monitoring and the collection of climatic data can be directed to solution of different problems, in accordance with which the principal goals can be formulated in the following way:

-- study of change in climate-forming factors, determination of their spatial-temporal variations, obtaining factual climatic data for use in organizing and guiding the economy -- agriculture, water management, construction and other directions in human activity;

-- understanding (includes analysis and evaluation) of natural and anthropogenic climatic changes and fluctuations (including study of climates of the past, comparison with state at the present time), changes in the state of the climatic system; determination of the critical factors operative in the direction of climatic changes (natural and anthropogenic factors) and critical elements of the biosphere, modification of which can most rapidly lead to climatic changes;

-- prediction of possible climatic changes and fluctuations, qualitative and quantitative predictions of changes and the climatic trend.

In order to solve these problems, in addition to the creation of a climatic monitoring system, it is necessary to carry out a broad research program, carry out modeling of climatic variations and changes. It must be emphasized that these directions are exceedingly closely related to one another.

Taking into account what has been said, the broad range of problems in the monitoring of climate and obtaining data relating to possible climatic changes and fluctuations can be broken down into the following sections:
a) measurement of the principal meteorological parameters, monitoring of the atmospheric phenomena and processes characterizing the corresponding regime of weather (climate); obtaining climatic data for use in organizing and conducting human economic activity;
b) monitoring of state of the climatic system, collection of data characterizing the reaction of the climatic system and its elements to natural and anthropogenic effects;
c) monitoring of factors (internal and external) exerting an influence on climate and the state of the climatic system and their sources. Here it is particularly necessary to discriminate the monitoring of anthropogenic factors;
d) monitoring of possible changes in the environment as a result of climatic changes and fluctuations (physical, ecological), monitoring of indirect indices of climatic variability;
e) obtaining additional characteristics necessary for the modeling of climate and a thorough analysis of the environment.

4. Monitoring of the Principal Hydrometeorological Parameters. Existing System

Section (a) includes data on weather received from meteorological stations and also from aerological and radar stations, from ships and aircraft. This includes measurements of air temperature (including daily extremal values), atmospheric pressure, air humidity, wind velocity and direction, intensity of precipitation, state of cloud cover (including the lower boundary). The measurements of the principal hydrometeorological parameters (sometimes in combination with additional measurements) make it possible to carry out monitoring of atmospheric phenomena and processes (turbulence, circulation). Thus, additional measurements of evaporation together with a number of the parameters enumerated above will make it possible to carry out observations of the moisture cycle.

In this section it is also necessary to include the collection of other climatic and regime data necessary for use in different aspects of human activity -- construction, agriculture, organization of transportation, power production, water management, etc. For this it is necessary to draw upon hydrological data, and also data on the snow cover, soil moisture content, data on soil freezing and some others. These data are obtained both at meteorological (climatological) stations and at hydrological stations and posts of national meteorological and hydrological services. According to approximate estimates, at the present time there are 40,000 climatological and 140,000 precipitation-measuring stations in operation in the world [10]. [The latter article describes and evaluates the global observation system. The observation system in the Soviet Union is a substantial contribution to such a system.]

The international exchange of basic weather data is the principal task of the World Weather Service (WWS) of the World Meteorological Organization (WMO). The World Weather Service consists of a global observation system, a global telecommunications system and a global data processing system.

World Weather System data are transmitted through the main transmission line of the global telecommunications system. The fundamental synoptic network of observation stations of the WMO, whose data are transmitted through the main transmission line, consists of approximately 2,500 surface, 725 rawin aerological and 720 radiosonde stations (1977) [3, 8]. Each day 2,600 shipboard weather summaries (from more than 7,000 vessels) and 3,000 aircraft weather summaries (1978) are received from regions of the world ocean.

Monthly climatological summaries with surface data are sent through the main transmission line from 1,572 wind stations ("CLIMAT" telegrams), and with aerological data -- from 509 stations ("CLIMAT-TEMP" telegrams) [3, 8]. Climatic data arriving from approximately 1,250 surface and 430 aerological stations are regularly published in the United States (Asheville) under the authority of the WMO. Data from meteorological satellites and data from rocket sounding of the atmosphere (to altitudes 60-80 km) are regularly transmitted. Section 9 of this article is devoted to satellite measurements.

A substantial broadening of observations of the parameters characterizing the state of the atmosphere and its interaction with the ocean will come about during the global meteorological experiment within the framework of the GARP program. Observations of the composition of the atmosphere can also be included in this aspect of monitoring. Here, evidently, one must include measurements of the atmospheric components subject to changes to such an extent that this can exert an appreciable influence on climate. As such atmospheric components we must presently include carbon dioxide (CO_2) and ozone (O_3) (in the stratosphere). Different impurities of natural and anthropogenic origin, electromagnetic radiations and thermal contamination can be regarded as factors exerting an influence on climate or the climatic system (see Section 6).

The number of precision stations observing changes in the content of atmospheric carbon dioxide is small (four). These observations are being made in places quite remote from local (natural and anthropogenic) sources of CO_2 (at base monitoring stations).

The monitoring of ozone is being carried out considerably more broadly. The exchange of data (WORLD OZONE DATA is being published in Canada) on the total quantity of ozone is being accomplished for approximately 80 stations. The vertical distribution of ozone according to data from ozonosonde observations is given for approximately 10 stations [14].

5. Monitoring of State of the Climatic System

Monitoring of the state of the climatic system is close to monitoring of the state of the biosphere as a whole (ecological monitoring), but it reveals only such interactions and effects which are directly related to climatic change. This includes monitoring of climate-forming factors and also parameters characterizing the reaction of the climatic system and its elements to different effects which can exert an influence on climatic changes.

This section should include, first of all: monitoring of state of the underlying surface (determination of albedo), energy and mass exchange between the atmosphere and the underlying surface; measurements of the area of sea, river and lake ice, glaciers; measurements of the area and the volume of the snow cover on a plain and in the mountains, surface of water features on the land; determination of the surface and biomass of the plant cover, area of zones turning to desert; measurements of the moisture content in the soil and vegetation, observation and study of circulation of waters of the ocean, optical properties and mass of the atmosphere, state of the ozonosphere.

Observations of the state of the atmosphere and its composition are quite fully overlapped by monitoring of the principal meteorological parameters and the other data described in Section 4.

Monitoring of the state of the ocean is ensured by measurement of the temperature of the sea surface and the subsurface layer, salinity and chemical composition of water, waves and currents at different depths. These measurements are made within the framework of the WMO World Weather Service/International Oceanographic Commission, using a large number of ships and a number of oceanic stations and buoys.

The study of interaction between the atmosphere and ocean is ensured by sea climatological measurements of air and sea temperature, dew point, visibility, wind direction and force, atmospheric pressure, cloud cover and waves (the exchange of information is accomplished under the code "SHIP"), as well as bathythermographic measurements of the subsurface ocean temperature. During a global international meteorological experiment similar measurements are made from additional ships, ocean stations and buoys.

The cryosphere considerably influences and sensitively reacts to different effects and climatic changes. In monitoring of the state of the cryosphere, in addition to monitoring of the snow cover, glaciers, sea, river and lake ice, there must be monitoring of zones of permafrost and determination of changes in these zones.

6. Monitoring of Climate-Forming Factors

The monitoring of factors exerting an influence on the state of the climatic system and climate (point "c," Section 3) and the sources of the modifying factors (reasons for the appearance or change in factors) is very important. The mentioned factors can be classified as external (relative to the earth's climatic system) and internal, and the sources of internal factors can be classified as natural and anthropogenic.

In this work the factors caused by the influence of the sun and cosmic radiations are classified as external factors. Among the solar effect factors we must include electromagnetic solar radiation in a broad spectral range (including ultraviolet radiation, hard electromagnetic radiation); corpuscular streams of different energies; the magnetic field. The intensity of the influencing factors is dependent on solar activity, the parameters of the earth's orbit, velocity of the earth's rotation. The effects of the influence are determined by the intensity of the modifying factors, the properties and composition of the earth's atmosphere, the properties of the earth's surface (albedo of the earth's surface).

Measurements of solar radiation are made by the world actinometric network (more than 900 stations [3]). Direct, scattered and reflected radiation is measured; integral atmospheric transparency is determined, as is albedo of the underlying surface; computations are made of total radiation, the balance of short- and long-wave radiation. The data are sent to the World Center in Leningrad where they are published annually.

Measurements of UV radiation are made by ozonometric stations; x-radiation and hard electromagnetic radiation and streams of solar corpuscular radiation are measured on artificial earth satellites; cosmic radiation is measured at special stations and from satellites.

Among the internal factors exerting an influence on climate and the climatic system we include heat discharges and the ejection (entry) of different substances into the biosphere or their redistribution among different media -- natural (eruption of volcanoes, weathering) and anthropogenic -- the release of heat when man uses energy, contamination of the biosphere, radiation of different anthropogenic sources. The enumerated modifying factors lead to changes in the properties of the climatic system: there is a change in the albedo of the underlying surface, heat and gas exchange. Changes in the state of elements of the climatic system -- change in the character of the underlying surface as a result of anthropogenic factors (creation of irrigation systems, plowing of the soil, change in the area of planted crops, urbanization) and natural factors (often in the presence of anthropogenic factors) -- change in the area of the snow cover and sea ice; change in the composition and properties (for example, transparency) of the atmosphere as a result of ejection of aerosol particles and different substances -- are climate-forming factors.

In some cases a number of the enumerated factors can be considered external relative to the part of the system where the effects of modification and change are determined. For example, a model in which the internal and external systems are different is examined in [17]. In that study, in addition to solar radiation, the surface characteristics of the land and the albedo of the vegetation cover are assigned to the external system.

Measurements of changes in the principal components of the atmosphere and contaminations are carried out at the national level in many countries; this type of measurements is a highly important component part of the global monitoring system.

Measurements of the background level of atmospheric contaminations are made in the network of background stations of the WMO, consisting of 176 stations, of which 75 transmit data on the chemical composition of precipitation as well and 60 transmit data on atmospheric turbidity [3].

In the development of monitoring special attention must be devoted to measurements of small impurities in the troposphere capable of exerting an influence on the ozone content in the stratosphere by means of a change in hydrogen, nitrogen and chlorine natural cycles. For this it is necessary to carry out measurements of freons (fluorochloromethanes), nitrous oxide, etc. Special measurements are being made of the aerosol component of the atmosphere; indirect data on aerosols are obtained in a comparison of direct and scattered radiation in actinometric observations. Heat discharges are evaluated on the basis of the temperature change (in the air and water) in the escape zone. Volcanic activity is carefully registered. A catalogue of all major eruptions of volcanoes on the earth is being compiled.

The climate-forming factors enumerated above are observed (can be observed) from artificial earth satellites (AES).

7. Monitoring of Consequences of Climatic Changes and Fluctuations

As noted, climatic changes and fluctuations can have a substantial effect on the state of the biosphere and the results of man's economic activity.

It is obvious that some effects in the biosphere arising as a result of climatic changes and fluctuations (change in moisture cycle, total biomass in ecological systems, etc.) can intensify or lessen the effect of other factors (as a result of the presence of positive or negative feedbacks). The organization of monitoring of such changes and the detection of such changes is an important new direction in monitoring. The changes arising in this case in elements of the climatic system, and the ecological consequences of climatic changes, in turn can be sensitive indices of the very fact of climatic change and the characteristics of such changes are frequently called indirect indices of climatic changes.

The elements of the biosphere most sensitive to climatic changes are those which are situated in the high latitudes (polar ice, tundra ecosystems, ecosystems of shelf polar zones), and also ecosystems of zones being transformed to deserts, lakes situated in arid regions.

Among the indirect climatic indices we can include changes in the levels of seas, lakes and rivers and shoreline changes; changes in the boundaries of natural zones, annual layers of bottom deposits of lakes and annual layers in glaciers; changes in the snow line and places of permanent accumulation of snow in the mountains and also the limits of occurrence of glaciers.

Here we can also include a series of ecological data: on change in the character of vegetation, the yield of different crops, population of insects, sea microflora and microfauna, on the nature of distribution of diseases of animals and plants, especially in zones with the greatest sensitivity to climatic changes. In organizing observations of such criteria it is necessary to exclude local anthropogenic effects of any character (for example, the level of a river or lake can decrease sharply as a result of removal of part of the runoff for irrigation).

Sometimes the need arises for obtaining additional data (such as those which were enumerated in the preceding sections) for carrying out a thorough analysis of the environment and carrying out the modeling of climate. On the other hand, thorough analysis and modeling make it possible to detect the most important (critical) modifying factors and the most sensitive elements of the biosphere (from the point of view of subsequent influence on climate), that is, to ensure complete scientific validation and optimization of the system of climatic monitoring and collection of data relating to climatic changes and fluctuations.

8. Problems of Priority and Accuracy in Measurements in Developing the Monitoring of Climate and a Service for Collecting Climatic Data

A determination of priorities in observations of the parameters and factors relating to climate and the accuracy of these observations are essentially dependent on the specific purposes for which the collected information is intended.

It is obvious that climatic information can be used (in accordance with the principal problems enumerated in Section 3):
-- for solving practical problems related to different directions in human activity -- in agriculture, construction, power production, city management, etc.;
-- for the modeling of climate for the purpose of determining the sensitivity of climate to changes in different parameters and prediction of possible climatic changes and fluctuations;
-- for detecting the onset of climatic changes;
-- for detecting the anthropogenic component of climatic change and determining the reasons (sources, factors) for such changes.

The choice of the parameters most important for solving different practical problems and the requirements on the accuracy of their measurement are determined for each direction in human activity, taking into account its specifics, technical level and regional peculiarities. This work is usually carried out by national meteorological services; the mentioned work is also carried out within the framework of the WMO. Here, evidently, it is necessary to go in the direction of filling the gaps in existing networks of climatological stations, the creation of climatic data banks.

An important problem is the choice of the parameters and determination among them of the priorities for the modeling of climate. This problem is being worked through in detail in connection with the second task of the Program for Investigation of Global Atmospheric Processes (GARP) [15].

Below we give a composite table (Table 1) reflecting the point of view expressed in [15] concerning the order of priority and the accuracy of measurements necessary at the present and in the future (during and after implementation of the International Global Experiment) for the modeling of climate (the necessary and desirable measurement accuracy values are given as the value intervals). The presented proposals were formulated as a supplement to the existing system of observations on the basis of the World Weather Service.

Table 1

Values (in Priority Sequence) and Required Measurement Accuracy Necessary for Purposes of Climatic Modeling

Measured Parameter	Accuracy
Radiation balance of "earth-atmosphere" system	2-15 W/m^2
Cloud cover	5% with respect to coverage, 1°C with respect to temperature of upper part
Surface temperature and heat content of active layer of ocean	0.5-1.5°C, 1-3 Cal/cm^2
Extent of snow cover and sea ice	resolution 50-100 km
Albedo of earth's surface	0.01-0.03
Precipitation over land and sea	1-3 mm/day
Soil moisture content and runoff from main river basins	10%
Temperature of soil and ice surface	1-3°C
Gas components of atmosphere and particles:	
ozone (total quantity, vertical distribution)	1-5% ±0.5 ppm, 2 km vertical
carbon dioxide	±0.1 ppm
tropospheric and stratospheric aerosols	5% by volume
atmospheric turbidity	1%
Wind shearing stress	0.1-0.4 $dyne/cm^2$

This work, in essence, is a formulation of the requirements on the accuracy of measurements of the developing (future) observation system, which, to be sure, can be used not only for the modeling of climate, but also for the other purposes formulated in Section 3 and the beginning of this section.

It is also necessary to measure sea level and the characteristics of surface currents, deep circulation in the ocean, thickness and drift of sea ice, and make observations of the polar ice caps (changes in boundaries and thicknesses).

In source [15], on the basis of which the table was prepared, we have indicated the required and desirable resolution of measurements in space and time, relatively uniform over the entire earth.

However, we feel that in the choice of the spatial and temporal resolution the priorities should also be determined. For example, the zones of the world ocean exerting an influence particularly strongly on some particular region (as this was demonstrated in a study by Marchuk [13]), must be covered by a more frequent (in time and space) network of observations. The accuracy in measuring the principal parameter -- temperature of the sea surface -- in such zones must be at least 0.2°C. Evidently, it is also necessary to carry out work for selecting sectors of small areas of the ocean, but representative of relatively large regions, for the organization of appropriate observations at these points.

In order to determine the possible climatic changes (including anthropogenic) it is necessary to select observations of changes in the state of elements of the biosphere most sensitive to changes in the climate of the biosphere (on a global and local scale) -- both direct and indirect indices of changes.

Recently published studies have given detailed descriptions of possible consequences and transformations of the most sensitive elements of the biosphere associated with possible changes in climate. The following can be considered indices of climatic change:
-- averaged air temperature, particularly for the high latitudes;
-- extent and limits of sea ice in the polar regions;
-- limits of glaciers in the high and middle latitudes;
-- level of internal seas and lakes;
-- precipitation and soil moisture content.

The most complex problem is discriminating the anthropogenic component of possible climatic changes, and also a search for the reasons for such changes. For these purposes it is necessary to define the elements most subject to anthropogenic influence -- some components of the radiation balance, atmospheric transparency, atmospheric content of different impurities, etc.

It must be remembered that it is easier to discriminate local anthropogenic changes in climate than global changes; it is easier to detect changes in the polar latitudes than in the middle or low latitudes.

In order to detect anthropogenic effects it is necessary to make observations with the greatest accuracy, established by means of modeling.

The development of a system for climatic monitoring and a service for the collection of climatic data should rest on already existing observation systems -- the national networks of climatological stations, the World Weather Service and also on different developing observation systems -- the national systems for observing the state of the environment, background and local contaminations, and on the global system for monitoring the environment. There is a need for a considerable filtering of the collected data; at the same time there must be filtering (by means of determining priorities) of the requirements imposed on the observation system and measurement accuracy.

Without question, the climatic monitoring system requires the organization of observations and evaluation of a number of characteristics and factors not provided for under the program of the enumerated systems.

Climatic monitoring and data service for climatic changes and fluctuations will require the development of very new technical observation means (especially remote, including the use of radars and lasers) and automated data processing systems. It is desirable to have a combination of surface observations and observations from space. An exceptional role in the development of such a system should be played by a satellite system.

9. Role of Satellites in Climatic Monitoring

The possibilities (and desirability) of using satellite systems for obtaining information on the earth's climate and the state of the climatic system can arbitrarily be broken down as follows:

1) measurement of meteorological parameters and obtaining other data important for understanding climatic fluctuations and changes in places where there are surface observation facilities;

2) measurements of these same parameters and collection of data in inaccessible (for surface measurements) regions -- in continental (a) and oceanic (b) regions;

3) measurements of parameters and factors hard to obtain or not subject to direct determination from the earth's surface:

   a) integral characteristics of the underlying surface (albedo, parameters characterizing energy- and mass exchange of the underlying surface with the atmosphere),
   b) some components of the radiation balance of the "earth-atmosphere" system (reflected solar radiation and long-wave outgoing radiation from terrestrial objects),
   c) corpuscular and hard electromagnetic solar and cosmic radiation;

4) use of satellites for routine transmission of data from inaccessible regions of the earth.

The priority (the order is indicated by Roman numerals) in use of the enumerated possibilities 1-3 for use of satellite systems, taking into account a functioning surface observation system, is represented as follows:

Type of satellite use	1	2a	2b	3a	3b	3c
Priority	III	II	I	II	I	I

At the present time satellites are used (or can be used) for making a number of highly important observations: cloud cover and wind fields; air temperature and humidity at different altitudes; temperature of the ocean surface; extent of boundaries of sea ice and the seasonal snow cover of the land; areas covered by vegetation (and the characteristics of their state) on the land or plankton in the ocean; soil moisture content, zones and intensity of precipitation; principal components of the radiation balance [2, 12, 16]).

The satellite subsystem is a part of the World Weather Service global observation system. The information is supplied from satellites situated in circumpolar and geostationary orbits.

Cloud cover fields have already been identified more than ten years; it is necessary to increase the accuracy in determining cloud cover altitude.

Temperature profiles are determined from an analysis of data on IR or microwave radiation in the absorption bands for gases with a known concentration (for example, carbon dioxide). The accuracy of the reconstructed profiles attains 2-3°C.

The determination of ocean surface temperature is made using radiation measurements in the IR range; the measurement accuracy is ±1-1.5°C and is limited by absorption by the cloud cover, by dust layers and other interference. It is necessary to emphasize the importance of determining the temperature of the ocean surface; using this parameter it is possible to make an approximate determination of the heat content of the active layer of the ocean and use this parameter for making quantitative judgments concerning the turbulent exchange of heat and moisture between the atmosphere and ocean. In this connection it is necessary to have an accuracy in determining temperature of the surface layer of the ocean to several tenths of a degree. The accuracy in determining temperature of the land was somewhat poorer than the accuracy in determining temperature of the ocean surface.

The boundary and extent of the ice and snow covers are determined in the visible range with sufficient accuracy. A combination of simultaneous observations in the visible and IR ranges makes it possible to determine different types of polar ice and measurements in the microwave range (in the region of wavelengths about 1.5 cm) make it possible, with a great accuracy, to distinguish regions covered by ice and open water, ice of different age and thickness.

Some surface properties (vegetation, quantity of plankton) are determined using multispectral photographs. The soil moisture content and precipitation can be determined using microwave radiometers. Satellites afford broad possibilities for measuring a number of characteristics of elements of the climatic systems and other parameters subject to anthropogenic influences. Anthropogenic influences can exert a substantial influence on atmospheric turbidity and favor an increase in atmospheric carbon dioxide, the appearance of impurities exerting an influence on the ozonosphere (freons, nitrous oxide). Dust layers (turbidity) are identified from satellites by means of photographing of the horizon region and the angular distribution and polarization of scattered solar radiation. The total quantity of some gaseous atmospheric components, such as water vapor, carbon dioxide and ozone can be determined using spectrometry of the absorption bands of radiated thermal and reflected solar radiation. It is also possible to determine the vertical distribution of ozone.

The interaction between the ocean and the atmosphere and the albedo of the ocean can be considerably influenced by contamination by petroleum products, the formation of films on the ocean surface impairing mass exchange between the ocean and the atmosphere. The detection of films from satellites is possible using multispectral photographs.

The fraction of satellite data in all the information on anthropogenic changes of the land surface is exceptionally great. Using data from satellites it is possible to evaluate the change in the vegetation cover as a result of cutting of forests, advance of deserts, and changes in the character of agricultural crops, which makes it possible to judge the reasons for changes in the albedo of the earth's surface. Effects associated with urbanization also exert an influence on albedo. Large irrigation structures and the redistribution of water resources exert an influence on the nature of the moisture cycle and surface albedo; changes in the snow cover in the neighborhood of cities and industrial regions are easily traced from satellites. All these data are obtained during the processing of satellite photographs (in different intervals of the visible and IR ranges). Suomi [17] proposes that the total quantity of released anthropogenic energy be determined on the basis of scattered electric light (at nighttime) (by statistically relating these two parameters).

The components of the radiation balance corresponding to reflected solar radiation (in the spectral range 0.3-3.0 μm) and the thermal radiation of the earth's surface (in the wavelength range 3-100 μm) are essentially dependent on anthropogenic factors (anthropogenic change in albedo of the earth's surface, intensity of thermal radiation of terrestrial objects).

All the radiation balance components are determined from satellites. Some components can be ascertained with better accuracy than from the earth's surface.

Anthropogenic changes in circumterrestrial space are also successfully determined by means of satellite observations. For example, the earth's radiation belts were determined by radiometric instruments mounted aboard a satellite.

10. Role of Monitoring in Formulating Criteria of the Admissibility of Anthropogenic Effects on the Climatic System

An analysis of possible anthropogenic climatic changes and fluctuations, the causes and sources of anthropogenic effects, directly or indirectly associated with climatic changes, in principle makes it possible to formulate the limits of such effects in which climate and the climatic system will be within the framework of natural fluctuations (for example, in the time interval of the last century) on global or local scales.

It is evident that such criteria can be formulated for a complex of effects and the individual most important factors (in such cases the intensity ratios of individual factors may be different when there is a fixed effectiveness of the overall result). For example, these criteria can be related to a limitation on the carbon dioxide concentration in atmospheric air, the rate of its entry into the atmosphere, limitation on the release of anthropogenic heat and different contaminants (such as freons) into the environment, setting limits on dust content of the troposphere and stratosphere. Nonadherence to such criteria can lead to appreciable climatic changes.

The formulation of such criteria implies a determination of the critical (potentially most dangerous) factors exerting an influence on the climatic system, a determination of the admissible degrees of influence on the most sensitive elements of the biosphere and the system as a whole.

The ability to discriminate such influences and effects by means of a monitoring system (in combination with the modeling of climate) and the timely adoption of measures of a scientific, technical and social character for the limitation of these effects within the framework of the formulated criteria will eliminate the danger of undesirable or even catastrophic climatic changes.

11. Summary

This article describes (and generalizes) current points of view of experts of different countries and international organizations with respect to the monitoring of climate and a service for the collection of climatic data [5, 10, 11, 14, 15, 17].

We have emphasized the need for discriminating from a great number of environmental characteristics and influences those which are most important and necessary for attaining the formulated goals -- obtaining climatic data for solving practical problems, determining the characteristics of state of the climatic system and factors influencing this state -- for studying and understanding climatic changes and fluctuations, discriminating anthropogenic influences and effects of climatic changes. The monitoring of changes in the biosphere associated with climatic changes is a new direction in monitoring.

The next task is a detailed working out of monitoring schemes for satisfying the enumerated purposes, as detailed as was the case for climatic modeling [15]. It is desirable to achieve the development and organization of such a monitoring system by means of which it would become possible (in combina-- tion with climatic modeling) to have reliable discrimination of anthropogenic and other influences and effects associated with the greatest impact on the biosphere (from the point of view of possible climatic changes) for the adoption of effective prophylactic measures directed against the onset of undesirable or even catastrophic climatic changes.

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CONCISE RESULTS OF THE WORLD CLIMATE CONFERENCE

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[Article by Candidate of Physical and Mathematical Sciences V. G. Boldyrev, USSR State Committee on Hydrometeorology and Environmental Monitoring, submitted for publication 10 April 1979]

Abstract: The author presents concise results of the work of the World Climate Conference, organized by the World Meteorological Organization and held in Geneva during the period 12-23 February 1979 and information on the principal recommendations of the conference. [The full name of the conference was: World Climate Conference — Conference of Experts on "Climate and Mankind".]

[Text] As is well known, 25 official reports were prepared for the World Climate Conference. Four of them were presented by Soviet scientists: Academician Ye. K. Fedorov, I. P. Gerasimov, G. I. Marchuk and Corresponding Member USSR Academy of Sciences Yu. A. Izrael'.

The presentation of reports began with the introductory words of the conference chairman R. White (United States), who noted the necessity for strengthening international cooperation for solving the problem of investigating climate and evaluating its tendencies and the importance of formulating recommendations on lessening the economic, social and other effects of climatic changes.

Academician Ye. K. Fedorov, in a report entitled "Climatic Changes and Mankind's Strategy," analyzed the natural and inadvertent anthropogenic changes in climate on regional and global scales, intentional modifications of climate and the influence of climatic changes on mankind (the basic content of this report by Ye. K. Fedorov is published in this number of the journal). The report of Ye. K. Fedorov caused enlivened discussion, during which a number of conferees supported the main content of the report.

A series of reports on the theme "The Global System Determining Climate" was opened with a report of the Swedish scientist B. Bolin entitled "Global Ecology and Man."

The report reflected the concern that human activity is exerting such an influence on regional and global processes in the biosphere that this is disrupting the established balance. The author examined global biogeochemical cycles -- carbon, nitrogen and sulfur -- and gave some evaluations of the possible modification of these cycles as a result of human activity. However, the author was extremely careful in his evaluations of the possible future state of the global ecological system. It is only asserted that since in general the relationship is known between climatic characteristics (temperature, precipitation) and types of biomes and soil, in the first approximation it is possible to determine how a land biote changes as a result of a climatic change. However, in the opinion of B. Bolin, a deterioration of state or destruction of an ecosystem can occur far more rapidly than a transition to some state optimum for the particular conditions. It is therefore concluded that a global change in climate in all probability is associated with a decrease in the productivity of the earth's ecosystem as a whole, although in individual regions productivity can increase.

The report of F. K. Hare (Canada), entitled "Climatic Change and Climatic Variability," summarized data on climatic variations at different time scales. The author took exceptional care to see to it that no unambiguous conclusion could be drawn from his report concerning the future behavior of the climatic system. In particular, in the author's opinion, it is unclear whether there will continue to be a tendency to a decrease in temperature observed during recent years. The author's objective, however, included emphasizing that regardless of the existence of any climatic trend there have occurred and will occur aperiodic climatic variations at relatively small time scales (some years). It is therefore important that there be no decline in interest in the problem of climatic variability and that constant preparations be made for inevitable climatic anomalies.

It should be noted that in the discussion of the report it was observed that there is a need for careful examination of statistical data in order to avoid incorrect conclusions. In particular, doubt was cast on the statements made during the last ten years concerning the increasing variability of climate.

Academician I. P. Gerasimov, in his report entitled "Climates of Past Geological Epochs," in addition to a review of paleoclimatic investigations, substantiated the concept of prognostic use of paleoclimatic data. I. P. Gerasimov emphasized that a study of paleoclimates provides initial data and creates scientific scenarios for formulating models of future climates. Thus, if a warming of climate occurs, according to paleogeographic data it is necessary to expect first the setting-in of an interglacial period climate, and then a climate similar to the climate of the Miocene-Pliocene, that is, a warm and moist climate, rather uniform over great areas.

A report by W. L. Gates (United States), entitled "Physical Principles of Climate," contained general definitions of a climatic system and the physical processes transpiring in this system. The author gave particular emphasis to the problem of climatic changes, but he noted that our knowledge of the physical principles of climate (satisfactory in themselves) nevertheless do not make it possible to explain the observed climatic changes. W. L. Gates emphasized the role of mathematical modeling for seeking such explanations and noted that under conditions of anthropogenic modification of climate modeling is the only method for evaluating the development of future climate.

The modeling of climatic changes and the problem of long-range weather forecasting was the subject of a report by Academician G. I. Marchuk (see this issue of the journal). In the discussion of the report many of the speakers supported the idea of G. I. Marchuk that it is necessary to create a system of hydrophysical observations for obtaining data for long-range weather forecasting models.

The resport by Corresponding Member USSR Academy of Sciences Yu. A. Izrael' presented the basic goals and problems in climatic monitoring, gave an analysis of the existing system and mentioned ways to improve the monitoring system (the basic content of the report by Yu. A. Izrael' is published in this number of the journal).

A report by R. Mann (Canada) and L. Machta (United States), entitled "Man's Activity Exerting an Influence on Climate," dealt with the following types of anthropogenic effects:
-- change in atmospheric composition;
-- discharge of heat into the atmosphere;
-- change in the physical and biological properties of underlying surfaces.

With respect to changes in atmospheric composition by means of discharge of gases and particles, the authors emphasize the influence of carbon dioxide, assuming that it is relatively great in comparison with the possible influence of nitrogen oxides, halocarbons, etc. However, in the opinion of the authors, at the present time it is difficult to determine the absolute values of climatic changes as a result of the influence of these gases by the use of numerical models.

It also follows from the report that the authors do not consider it possible to indicate precisely the sign of temperature change of the "earth-atmosphere" system due to the influence of an increase in the concentration of particles in the atmosphere. In exactly the same way, in an examination of processes in the stratosphere the authors only enumerate the possible mechanisms of stratospheric disturbance and the possible reasons for change in ozone content; no conclusion is drawn as to whether an increase or decrease of stratospheric ozone should be expected.

In summarizing modern estimates, R. Mann and L. Machta conclude that on a global scale the energy produced by man is only a small part of the solar energy incident on the earth's surface. However, on a local or even on a regional scale the quantities of solar energy and heat of anthropogenic origin can be comparable.

In a discussion of the influence of properties of the underlying surface on climate the authors again limit themselves to an enumeration of the possible ways in which this influence is exerted without drawing quantitative conclusions concerning the magnitude of climatic changes. However, it can be concluded that the influence of changes in the characteristics of the underlying surface is manifested for the most part on local and regional scales.

As already noted, the authors separately examine the question of the influence of change in the content of carbon dioxide in the atmosphere on climate. Citing well-known data on increase in the concentration of atmospheric carbon dioxide in the atmosphere during recent decades, model estimates of its future content and the results of computations of possible climatic changes, the authors assert that the difficulties in modeling of climate do not make possible a reliable prediction of climatic changes.

The general conclusions from the report are as follows:
-- local and regional climates can be changed as a result of man's activity;
-- although the chemical composition of the atmosphere on a global scale can be changed by man, there is no proof that man's activity exerts an influence on global climate (it is possible that this influence exists, but for the time being remains undiscovered).

B. J. Mason (Great Britain) devoted a large part of his report, entitled "Some Results of Climatic Experiments With Numerical Models," to an exposition of the results of computations of reaction of the climatic system to different natural and anthropogenic disturbances. For numerical experiments use was made of different models of the atmosphere developed by the British Meteorological Service. In many cases the author limited himself to an exposition of earlier published results of numerical experiments carried out in other countries. Here it is of interest to cite some conclusions drawn by the author concerning the influence of anthropogenic effects on climate:
-- an increase in the concentration of stratospheric aerosols does not exert a significant influence on the temperature regime at the earth's surface; on this basis it is asserted that the coolings of climate in the past scarcely were caused by the eruptions of volcanoes;
-- a decrease in the stratospheric concentration of ozone does not lead to appreciable changes in temperature and precipitation in the lower atmosphere.

With respect to the possibilities of changing the ozone concentration as a result of human activity, in the report it is asserted that:

-- the principal factor destroying the ozone layer is the ejection of halocarbons (freons) into the atmosphere; nitrogen oxides exert a far lesser influence on ozone;
-- an increase in the carbon dioxide concentration is leading to an increase in the ozone concentration, which to a definite degree can compensate for the destructive influence of halocarbons.

However, it is clear that these results, obtained in experiments for determining the sensitivity of climate to different factors, are in need of careful checking with the use of more modern models taking into account the entire complex of interactions in the climatic system.

General considerations with respect to the evaluation of future climate were expressed in the report by H. Flohn (West Germany) entitled "Pattern of Probable Future Climates -- Natural and Artificial." The report describes different warm and cold periods in the past, but in essence nothing is said about which of these variants may come to pass in the future. In addition, it is asserted that the use of examples of past climates for evaluating future climatic conditions is limited due to changing boundary conditions. H. Flohn, however, assumes that if a cooling does not set in, caused by strong volcanic eruptions of recent years (after 1948), in the coming century there is a great probability of a warming as a result of the "greenhouse effect" of carbon dioxide and other gases.

Finally, the last of the group of reports describing man's influence on climate and in one way or another giving an evaluation of future climate was a report by J. Williams, W. Hafele and W. Sassin (International Institute of Applied Systems Analysis) entitled "Energy and Climate. A Review With Emphasis on Global Effects." The authors examined three sources of global influence on climate: ejection of heat into the atmosphere, change in conditions at the earth's surface and change in the concentration of atmospheric gases (especially carbon dioxide). It was concluded in the report that the first two sources should not exert an influence on global climate. In the opinion of the authors, an increase in the CO_2 concentration must be regarded as the principal influencing factor, although the knowledge of the carbon cycle and the climatic system as a whole is still inadequate for making definite recommendations of an ecological nature, in particular, recommendations on the use of fossil fuel.

In summarizing the conclusions from the above-mentioned reports, devoted to a general description of behavior of the climatic system and an evaluation of the influence of man's activity on climate, it is possible to note the following:
-- the authors assume that the level of knowledge of climate and climatic models is inadequate for describing all the complex nonlinear interactions within the climatic system;
-- there are different, sometimes diametrically opposite points of view concerning evaluation of the influence of anthropogenic factors on climatic change;

-- although it is recognized that an increase in the content of atmospheric carbon dioxide can be potentially the most powerful source of anthropogenic influence on climate, great caution must be exercised in determining whether this influence is real, and especially in its quantitative evaluation.

The remaining reports presented at the conference related to the influence of climate on mankind -- on different branches of the economy and the world economy in general. Reports were also presented on the interrelationship between climate and water resources, the influence of climate on agriculture and forestry, land use and fishing, etc.

A joint report by J. Schaake (United States) and Z. Kaczmarek (Poland) was entitled "Climatic Variability and Planning and Operation of Water Management Systems." In examining the principal types of hydrological models employed in evaluating and predicting river runoff, the authors noted a shortage of climatic data, including data on river runoff, over a quite long period. The report gave no evaluations of change in the geographic regime in dependence on the change in climatic conditions.

"Climate, Health and Disease," such was the theme of a report by W. Weikhe (Switzerland). The report had the nature of a review and for the most part contained a description of ways in which climate influences man's performance, his nutritional requirements, habitat, incidence of disease, etc.

A large group of reports was devoted to the influence of climate on agriculture. M. S. Svaminatkhan (India), in a report entitled "Global Aspects of Food Production," examined the meteorological conditions as only one of the factors exerting an influence on agricultural productivity, devoting relatively little attention to this factor. To all intents and purposes the author extrapolated existing climatic conditions for some period for the purpose of an analysis of future possibilities of food production and solution of social problems.

D. D. MacQueeg (United States), in a report entitled "Climatic Variability and Agriculture in Regions of Temperate Climate," emphasized that the existing world system of agricultural production is extremely sensitive to significant climatic anomalies and will remain so in the future, at least with respect to year-to-year climatic variability. The author mentioned the importance of disseminating the corresponding climatic information and the know-how for using it.

The influence of climate on agricultural productivity was also examined in the reports of H. Fukui (Japan), entitled "Variability of Climate and Agriculture in Moist Tropical Regions" and F. Mattei (Italy), entitled "Climatic Variability and Agriculture in Semiarid Tropical Regions."

H. Fukui shares the point of view that existing agricultural production is extremely sensitive to climatic changes, especially to a change in the quantity of precipitation. In the author's opinion, the dependence of agricultural production in the tropical regions on the annual quantity of precipitation for the most part is governed by a high total evaporation in the economically most active parts of the moist tropics. Since agricultural techniques in these regions are at a level far from the optimum, and since the necessary expansion of agricultural production is ensured and in the immediate future will be ensured here by an expansion of sown areas, and not by an intensification of production, the sensitivity of agriculture to a change in the quantity of precipitation will remain as significant as it is now, or will even increase.

F. Mattei noted that the so-called semiarid regions are characterized by a lower level of crop yields than the zones of temperate climate and agriculture in these regions, moreso than in others, is subject to the influence of climatic variability. Regarding the quantity of precipitation during the summer rainy season as the principal characteristic of the year-to-year variability of climate in these regions, the author gives some recommendations (quite obvious) directed to an increase in the stability of agricultural systems to the influence of climatic variability.

Thus, all three speakers, examining problems in the influence of climate on agriculture in different climatic zones, assumed that at the present time agricultural productivity is still to a high degree dependent on climatic conditions and that this dependence can scarcely be reduced in the immediate future.

A special subject in the series of reports devoted to the general problems of the influence of climate on human activity was dealt with in a report by a group of Chinese scientists entitled "Study of Climatic Change and Clarification of Climatic Resources in China," having an informative character.

Another report, having a regional character, was a report by D. Burgos (Arentina) entitled "Renewable Resources and Agriculture in Latin America in Relation to Climatic Stability."

The problems of land use in relation to climatic stability were examined in a report by D. Oguntoinbo (Nigeria) and R. Odingo (Kenya), to be sure, only applicable to Africa (the report has the subtitle "African Perspectives"). Citing data on the cyclicity of the quantity of falling precipitation, the authors noted that the increase in droughts in recent years is associated to a high degree with human activity destructive for the ecosystem: the annihilation of forests, burning of the savanna, increase in pasture area, etc. The authors emphasized that in Africa the influence of man on land productivity has reached a level comparable with the level of the influence of natural climatic variations. Therefore, climatic fluctuations have increased; however, there is no basis for assuming that there is a long-range trend to the setting-in of a more arid climate.

In a report entitled "Climatic Variability and Forestry," A. Baumgartner (West Germany) discussed both the influence of climatic changes on the state of forests and the influence of forests on the formation of climate and the environment. The author assumes that with the existing level of knowledge concerning the interrelationship between forests and climate it is necessary to do everything possible in order to retain the existing forest cover because the possible consequences of a decrease in the area of forests are still not entirely clear and due to the ecological, economic and social role of the forest.

The problems involved in the influence of climatic changes on sea fishing were examined in a report by D. Cashing (Great Britain). Related to this report was an article by R. Welcome (Food and Agricultural Organization) entitled "Influence of Climatic Changes on Fishing in Internal Waters." The report demonstrated that although it is possible to assume the presence of a relationship between the year-to-year variability of climate and the change in the number of schools of fish in individual regions, this relationship has not yet been determined quantitatively. In exactly the same way, the relationship between long-period (about 100 years) variations in the number of fish and climatic fluctuations is not entirely clear.

T. Haskell (Great Britain) presented a report entitled "Climatic Variability, Sea Resources and Exploitation of the Coastal Zone." The author noted that from the point of view of the exploitation of sea resources two aspects of a knowledge of climate are of importance: paleoclimatic information necessary in the exploitation of petroleum reserves, manganese nodules and other minerals, and data on present-day climate (with an evaluation of future climate), necessary for the exploitation of deposits and the transport of freight, including the production of petroleum. In the report special attention is devoted to the problems involved in the influence of possible petroleum leakage on climate and the rather optimistic conclusion is drawn that with the existing volumes of petroleum entering the ocean there is no danger of an unfavorable influence of this factor on the animal world and planetary climate. However, the author nevertheless could not deny the existence of serious social and ecological consequences of contamination of the ocean by petroleum.

The last two reports related to the general problems involved in the interrelationship between climate and the world economy and the life of human society. The first of these, entitled "Climate and Economic Activity" (author R. D'Arcy, United States) was officially included in the conference program in advance; the second, "Climate and Society: Lessons from Recent Events" was presented directly before the beginning of the conference and must be regarded as an additional communication.

R. D'Arcy, taking note of the incomplete knowledge of processes of interactions within the climatic system and the magnitudes of the possible anthropogenic changes, concluded that at the present time there is no basis for in any way exerting an influence on existing human activity for the purposes of preserving climate. However, he asserted that even now it is necessary to intensify scientific research for the purpose of evaluating the possible influence of climatic changes and proposed that some agency be created within the framework of the UN which would be capable of defining those types of activity which potentially can cause climatic changes and which could recommend measures for preventing unfavorable consequences. The author had the developing countries primarily in mind.

As examples of the economic evaluations related to climatic changes, R. D'Arcy cited sample values of the additional expenditures (advantages) caused by a decrease in the mean global temperature by 1°C or its increase by 0.5°C (with and without a change in the quantity of precipitation), and also an analysis of the type "expenditures-income" in connection with possible stratospheric contamination as a result of the flights of supersonic aircraft, escape of halocarbons and use of nitrogen fertilizers. Also touched upon was the economic aspect of a possible warming associated with an increase in the atmospheric carbon dioxide content. However, the author constantly emphasized that all the mentioned evaluations are strictly preliminary. In addition, these evaluations were made assuming the existence of the current economic and political structure. Therefore, the author considers them applicable only in the case of not excessively great deviations of climate from the existing state because significant deviations would so greatly alter the existing structure of the economy that it would be impossible to evaluate, even approximately, possible quantitative and qualitative changes.

The report led to a lively discussion, during which it was noted, in particular, that the dependence of expenditures or benefits on climate is not the same for different economic and social systems.

An additional communication by R. Cates, entitled "Climate and Society: Lessons from Recent Events," was based on the approach to frequently repeating dangerous weather phenomena as to climatic phenomena. The author cited evaluations of the losses inflicted on different countries by dangerous weather phenomena (floods, tropical cyclones, tornados, etc.) and called for drawing up of a plan of action based on already available information concerning the state of the climate. However, in essence, the author could not make constructive proposals as to what such a plan should include. The report repeatedly mentioned the fact that in "rich" (the author's terminology) countries the consequences of dangerous weather phenomena can be decreased and the losses of human life can be reduced to a minimum, but the author has not demonstrated (and indeed could not demonstrate) how the "poor" countries could achieve the same results.

In the discussion of the communication by R. Cates it was noted that the author is scarcely thoroughly familiar with the theories of development of human society, especially with the Marxist theory. It was also noted that in the absence of a truly social approach to study of the interrelationship between climate and human society any considerations of this problem will have a superficial character; in general, only a society actually having interests and goals which are common for all its members, is capable of correctly evaluating the developing situation and formulating specific programs of action.

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The last session of the first week of the conference was devoted to a general discussion and also to organization of work for the second week. The following working groups were formed:
I -- Climatic Data and Use of Climatic Knowledge.
II -- Influence of Society on Climatic Change and Variation.
III -- Influence of Climatic Changes and Variations on Society.
IV -- Investigation of Climatic Changes and Variations.

The task of the working groups included the preparation of documents summarizing the existing state of matters and the formulation of recommendations which could be taken into account in planning the World Climate Program.

The document of the first working group, relating to climatic data, included recommendations concerning the collection, on a global basis, of meteorological, aerological, oceanographic and hydrological data, data on atmospheric chemistry and data on stratospheric dust and geomorphology. The remaining types of data were put into the section "Need of Data for Investigating the Effects of Climate on Human Activity" and it was indicated that they must be stored in national archives and used at the national level. In addition, in the document special emphasis is placed on the need for creating a network of climatic observations for the oceans. In the document of this same working group, describing the application of climatic knowledge, the following types of international activity were included (in order of priority).

It was decided to put in first place such an important matter, having general importance, as the development of a data base; second -- a program for training personnel; third -- the dissemination of methodology to the developing countries; fourth -- cooperation in the use of climatic knowledge. The information used for ensuring climatic applications must be collected, primarily, at the national level and only some international projects require global data.

The second working group, in its report, noted the different types of human activity capable of exerting an influence on climate. The group did not deem it possible to give quantitative evaluations of climatic changes as a result of various factors, but indicated the need for an international coordinated research program for the purpose of obtaining such an evaluation.

An important matter considered by the third working group was the matter of a plan of actions for study of climatic effects on society. The group could not arrive at a unanimous opinion concerning this plan. A majority of those present at the plenary session agreed with this and recommended that a group of experts of an interdisciplinary character, with the cooperation of interested international governmental and nongovernmental organizations, prepare a more detailed plan of actions and a scientific program.

The fourth working group examined priorities in the field of scientific research. The group decided that one of the most important research problems is a study of the problems involved in interaction between the ocean and the atmosphere. The problem of the influence of an increase in CO_2 on climatic change was not included by the group as the dominant problem, but together with the influence of an increase in ozone and chlorine compounds.

The climate research program also included sections on solar-terrestrial relationships and paleoclimate.

During the second week work was continued on the basic document of the conference -- its Declaration. The final text of the declaration was adopted at the final session of the conference. [See this number of the journal.]

In connection with everything which has been said it must be noted that the World Climate Conference was a highly important event in international scientific life.

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EVALUATING THE PARAMETERS OF DISCRETE MODELS OF DYNAMICS OF THE ATMOSPHERE AND OCEAN

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[Article by Doctor of Physical and Mathematical Sciences V. V. Penenko, Computation Center Siberian Department USSR Academy of Sciences, submitted for publication 21 September 1978]

Abstract: The article describes a method for evaluating the state and parameters of discrete models of dynamics of the atmosphere and ocean on the basis of measurement data. The basis for the method is the ideas of the theory of optimization and identification of complex systems. The base elements of the computation algorithm are the procedure of computation of the gradients of the functionals in parameter space and state space and expressions relating the changes in the parameters and the criterion of model quality. The author discusses the practical applications of the proposed method.

[Text] Mathematical models of dynamics of the atmosphere and ocean, describing the behavior of real physical systems, contain a number of parameters whose values are known extremely approximately or are completely unknown. By "parameters" is meant the coefficients of the differential equations, the field of initial values, the characteristics of the integration regions, etc. In solving specific problems the values of these parameters are stipulated approximately from some region of admissible values. In a general case some parameters, such as the turbulence coefficients, the coefficients determining interaction between the atmosphere and underlying surface, and others, are functions dependent on space coordinates, time and on the sought-for values describing the state of the system. Thus, the mathematical model can be unclosed, and for its closing it is necessary to obtain additional information or make additional assumptions determining the feedback between the state of the system and the parameters. In this connection the problem arises of evaluating the state of the system and the parameters of the models on the basis of a priori information and measurement data.

The article describes a method for evaluating the state and parameters of discrete models of dynamics of the ocean and atmosphere using a stipulated criterion. If data are available from measurements of system state, the method operates in a diagnostic regime, that is, there is an evaluation of the parameters and assimilation of the measured information. Otherwise there is an adjustment of the parameters using some criterion characterizing the quality of the model. The basis of the method is the ideas of optimization, identification and modeling of complex systems [4, 6, 11, 12], regularization and optimum filtering [1, 11]. Some aspects of this method applicable to the considered class of problems are set forth in [7-10].

We will assume that the structure of the mathematical model is stipulated and is determined by a system of nonlinear differential equations in partial derivatives expressing the principal laws of hydrothermodynamics of the modeled processes. For convenience in exposition we will write the model in operator form

$$B\frac{\partial\vec{\varphi}}{\partial t}+L(\vec{\varphi},\ \vec{Y})=0,\quad \vec{\varphi}\in Q(D_t),\quad \vec{Y}\in R(D_t),\tag{1}$$

where $\vec{\varphi}$ is the vector of state of the system, $\vec{Y}$ is the vector of model parameters, B is a diagonal matrix, in the case of stationary models a zero matrix, $L(\vec{\varphi}, \vec{Y})$ is a nonlinear matrix operator, dependent on the vector of state and the vector of parameters, $D_t = \{D \times [0, \bar{t}]\}$ is the region of change of space coordinates and time, $Q(D_t)$ is the space of functions satisfying the boundary and initial conditions, to which the solution of the problem belongs, $R(D_t)$ is the set of admissible values of the input parameters of the models.

The mathematical modeling process includes several stages: investigation of the solubility of the problem (1), forming of discrete analogues and formulation of a computation algorithm, investigation of behavior of the model in the region $\{(\vec{x}, t) \in D_t, \vec{Y} \in R(D_t)\}$ and its sensitivity to variations of the input parameters and external effects, and identification of the parameters on the basis of measurement data. The computation algorithm for solution of the problem (1) actually realizes the transformation

$$\vec{\varphi}=\vec{\varphi}(\vec{x},\ t,\ \vec{Y}),\quad (\vec{x},\ t)\in D_t,\quad \vec{Y}\in R(D_t),\tag{2}$$

determining the vector of state of the model as a function of the independent variables and input parameters.

The quality criterion for the model and the methods for realizing it can be some functional characterizing the model as a whole or the measure of deviations between the measured and computed values of the vector of state components. We will denote this functional by $\Phi(\vec{\varphi}, \vec{\varphi}_m)$, where $\vec{\varphi}$ is the vector of state, computed using the model, $\vec{\varphi}_m$ are the values of the vector of state obtained as a result of measurements in a real system. The components of the vector $\vec{\varphi}_m$ are determined in the discrete set of points $D_t^m < D_t$. In actual practice it is customary to use several criteria for evaluating model quality.

The process of forming discrete analogues and computation algorithms is considerably simplified if instead of a problem in a differential formulation (1) we examine its variation formulation in the form of an integral identity following from determination of the generalized solution, that is

$$I(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*) = 0, \qquad (3)$$

where $\vec{\varphi}^* \in Q^*(D_t)$ is some arbitrary sufficiently smooth vector-function of the same structure as $\vec{\varphi}$. The functional on the left-hand side of (3) is selected in such a way that with a special stipulation of $\vec{\varphi}^*$ from (3) directly without additional operations of differentiation and integration by parts we obtain an equation for the total energy of the system. The discretization of model (1) involves forming of the discrete analogue (3)

$$I^h(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*) = 0, \qquad (4)$$

and in the writing of the conditions for the stationary state of the summing functional $I^h(\vec{\varphi}_*, \vec{Y}, \vec{\varphi}^*)$ with arbitrary and independent variations of the function $\vec{\varphi}^*$, that is

$$\frac{\partial}{\partial \vec{\varphi}^*} I^h(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*) = 0. \qquad (5)$$

The system (5) is a discrete analogue of the problem (1). In addition to the system of fundamental equations (5) we will write a system of conjugate equations in discrete form, which is obtained from the conditions

$$\frac{\partial}{\partial \vec{\varphi}} I^h(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*) = 0. \qquad (6)$$

In an example we will clarify the sense of the introduced definitions. We will examine a nonadiabatic model of atmospheric hydrothermodynamics in isobaric coordinates on a spherical earth [3]

$$\frac{du}{dt} + \frac{\operatorname{ctg}\vartheta}{a} uv + lv + \frac{1}{a\sin\vartheta}\frac{\partial H}{\partial\psi} - F_u = 0, \qquad (7)$$

$$\frac{dv}{dt} - \frac{\operatorname{ctg}\vartheta}{a} u^2 - lu + \frac{1}{a}\frac{\partial H}{\partial\vartheta} - F_v = 0, \qquad (8)$$

$$\frac{dT}{dt} - \frac{(\gamma_a - \gamma) R\overline{T}}{gp}\tau - F_T - \frac{\tilde{\varepsilon}}{c_p} = 0, \qquad (9)$$

$$\frac{\partial H}{\partial t} + \frac{RT}{p} = 0, \qquad (10)$$

$$\frac{1}{a\sin\vartheta}\left(\frac{\partial u}{\partial\psi} + \frac{\partial(v\sin\vartheta)}{\partial\vartheta}\right)\frac{\partial\tau}{\partial p} = 0, \qquad (11)$$

where

$$\frac{d\varphi}{dt} = \frac{\partial\varphi}{\partial t} + \vec{u}\operatorname{grad}\varphi \equiv \frac{\partial\varphi}{\partial t} + \frac{u}{a\sin\vartheta}\frac{\partial\varphi}{\partial t} + \frac{v}{a}\frac{\partial\varphi}{\partial\vartheta} + \tau\frac{\partial\varphi}{\partial p} \quad (\varphi = u,\ v,\ T),$$

t is time, ψ is longitude, ϑ is complement to latitude, p is pressure ($p_T \leqslant p \leqslant p_a$, p_T is pressure at the upper, and p_a is pressure at the lower boundaries of the air mass), a is the earth's radius, $\vec{u} = (u, v, \tau)$ is the velocity vector, u, v, τ are the components of the velocity vector in the direction ψ, ϑ, p respectively, T and H are the deviations of temperature and geopotential from their standard values $\bar{T}$ and $\bar{H}$, γ_a is the adiabatic temperature gradient, $\gamma = -\partial \bar{T}/\partial z$ is the standard temperature gradient, ε is the heat influx to a unit volume, c_p is the specific heat capacity at constant pressure, R is the universal gas constant, l is the Coriolis parameter, g is the acceleration of free falling, F_α (α = u, v, T) are expressions describing turbulent exchange processes.

We will represent F_α (α = u, v, T) in the form of the sum of two terms:

$$F_\alpha = F_\alpha^\nu + F_\alpha^s, \qquad (12)$$

where the subscripts ν and s denote terms describing turbulent processes in the vertical and horizontal directions.

We will determine F_α^ν in the following way:

$$F_\alpha^\nu = \frac{\partial}{\partial p} \chi_\alpha \frac{\partial \alpha}{\partial p}, \quad \chi_\alpha = \nu_\alpha \left(\frac{gp}{R\bar{T}}\right)^2 (\alpha = u,\ v,\ T),\ \nu_u = \nu_v = \nu_1,\ \nu_T = \nu_2, \qquad (13)$$

where ν_i(i = 1, 2) are the coefficients of vertical turbulent exchange.

For describing the turbulent exchange operators in horizontal directions we will use the following expressions:

$$F_T^s = \frac{1}{a^2 \sin^2 \vartheta} \frac{\partial}{\partial \psi} \mu_2 \frac{\partial T}{\partial \psi} + \frac{1}{a^2 \sin \vartheta} \frac{\partial}{\partial \vartheta} \mu_2 \sin \vartheta \frac{\partial T}{\partial \vartheta}, \qquad (14)$$

$$F_u^s = \frac{1}{a \sin \vartheta} \frac{\partial}{\partial \psi} (\mu_1 D_T(\vec{u}_s)) - \frac{1}{a} \frac{\partial}{\partial \vartheta} (\mu_1 D_s(\vec{u}_s)), \qquad (15)$$

$$F_v^s = \frac{1}{a \sin \vartheta} \frac{\partial}{\partial \psi} (\mu_1 D_s(\vec{u}_s)) + \frac{1}{a} \frac{\partial}{\partial \vartheta} (\mu_1 D_T(\vec{u}_s)), \qquad (16)$$

where

$$\vec{u}_s = (u,\ v),\ D_T(\vec{u}_s) = \frac{1}{a \sin \vartheta} \left(\frac{\partial u}{\partial \psi} + \frac{\partial (v \sin \vartheta)}{\partial \vartheta}\right),$$

$$D_s(\vec{u}_s) = \frac{1}{a \sin \vartheta} \left(\frac{\partial v}{\partial \psi} - \frac{\partial (u \sin \vartheta)}{\partial \vartheta}\right),$$

μ_i(i = 1, 2) are the coefficients of horizontal turbulent exchange.

System (7)-(11) will be solved in the region

$$D_t = \{D \times [0, \bar{t}]\},\quad D = \{S \times [p_T,\ p_s]\},\quad S = \{0 \leqslant \psi \leqslant 2\pi, \qquad (17)$$

$$0 \leqslant \vartheta \leqslant \pi\}$$

with the following boundary conditions:

with $$p = p_T \quad \tau = 0,\quad \chi_1 \frac{\partial u}{\partial p} = \chi_1 \frac{\partial v}{\partial p} = 0,\quad \chi_2 \frac{\partial T}{\partial p} = 0; \qquad (18)$$

with $$p = p_a \quad \tau = \bar{\rho}\left[\frac{\partial H}{\partial t} + \frac{u}{a \sin \vartheta}\frac{\partial}{\partial \psi}(H - gZ) + \frac{v}{a}\frac{\partial}{\partial \vartheta}(H - gZ)\right],$$

$$\chi_1 \frac{\partial u}{\partial p} = -\sigma_\psi, \quad \chi_1 \frac{\partial v}{\partial p} = -\sigma_\vartheta, \quad \chi_2 \frac{\partial T}{\partial p} = -q_s, \tag{19}$$

where $Z = Z(\psi, \vartheta)$ is a function describing the relief of the underlying surface, $\bar{\rho}$ is the standard density value, σ_ψ, σ_ϑ, q_s are functions determining the regime of interaction between the atmosphere and the underlying surface.

In addition to conditions (18), (19), the periodicity of all functions of the variable ψ with the period 2π is assumed, that is

$$\varphi(\psi + 2\pi, \vartheta, p, t) = \varphi(\psi, \vartheta, p, t). \tag{20}$$

At the poles we will assume that none of the scalar functions are dependent on the ψ coordinates, that is

$$\varphi(\psi, \vartheta_\alpha, p, t) = \varphi(\vartheta_\alpha, p, t) \quad (\vartheta_\alpha = 0, \pi), \tag{21}$$

and the velocity vector components form a one-parameter rotation group continuously dependent on ψ:

$$\begin{aligned} u(\psi, \alpha, p, t) &= U(\alpha, p, t)\cos\psi - \cos\alpha\, V(\alpha, p, t)\sin\psi, \\ v(\psi, \alpha, p, t) &= U(\alpha, p, t)\cos\alpha \sin\psi + V(\alpha, p, t)\sin\psi \ (\alpha = 0, \pi). \end{aligned} \tag{22}$$

Here $U(\alpha, p, t)$, $V(\alpha, p, t)$ are the components of the velocity vector in fixed local bases corresponding to the ψ reference points with $\vartheta = 0, \pi$.

For solving the problem it is necessary at the initial moment in time t = 0 to stipulate the functions u, v, T in the region D and $H(p_a)$ in S. The functions $H(p)$ with $p < p_a$ and τ with t = 0 can be determined from the hydrostatics and continuity equations.

Comparing now the formulation of the problem in operator form with the system (7)-(11), we can determine the vector of state in the form $\vec{\varphi} = (u, v, T, H, \tau)$ and the vector of parameters

$$\vec{Y} = (\vec{\varphi}^0, \tilde{\varepsilon}, \mu_1, \mu_2, \nu_1, \nu_2, \sigma_\psi, \sigma_\vartheta, q_T, z, \bar{T}, \bar{\rho}, (\gamma_a - \gamma)),$$

where $\vec{\varphi}^0$ is the vector of state of the system at the initial moment in time t = 0. Among the components of the vector $\vec{Y}$ it is also possible to include (a, c_p, R, l). The B matrix has the form B = diag $\{1, 1, 1, 0, 0\}$, and the operator $L(\vec{\varphi}, \vec{Y})$ is determined by the system of equations (7)-(16), if the local time derivatives are excluded in them.

For the considered model we introduce the integral identity (3) in the following way [9]:

$$I(\vec{\varphi},\ \vec{Y},\ \vec{\varphi}^*) \equiv \int\limits_{D_t} (\Lambda u,\ u^*) + (\Lambda v,\ v^*) + \sigma(\Lambda T,\ T^*) +$$

$$+ (\vec{u}^* \operatorname{grad} H - \vec{u} \operatorname{grad} H^*) + \left(l + \frac{\operatorname{ctg}\vartheta}{a}\, u\right)(u^* v - u v^*) +$$

$$+ \frac{R}{p}\left(T\tau^* - \sigma\frac{(\gamma_a - \gamma)}{g}\, \overline{T}\tau T^*\right) - \frac{\sigma\tilde{\varepsilon}}{c_p}\, T^* \Bigg\} dD\, dt + \tag{23}$$

$$+ \int\limits_{S_t} \frac{1}{2}\, \overline{\rho}\left(\frac{\partial H}{\partial t} H^* - \frac{\partial H^*}{\partial t} H\right)\Bigg|_{p=p_a} dS\, dt + \frac{1}{2}\left[\int\limits_{D} (u u^* + v v^* + \sigma T T^*)\, dD +\right.$$

$$\left. + \int\limits_{S} \overline{\rho} H H^* \Bigg|_{p=p_a} dS\right]\Bigg|_0^t + I_D(\vec{\varphi},\ \vec{\varphi}^*) = 0,$$

where

$$I_D(\vec{\varphi},\ \vec{\varphi}^*) = \int\limits_{D_t} \Bigg\{ \mu_1 \Big[D_T(\vec{u}_s)\, D_T(\vec{u}_s^*) + D_s(\vec{u}_s)\, D_s(\vec{u}_s^*) +$$

$$+ \chi_1\left(\frac{\partial u}{\partial p}\frac{\partial u^*}{\partial p} + \frac{\partial v}{\partial p}\frac{\partial v^*}{\partial p}\right) + \sigma\left[\chi_2 \frac{\partial T}{\partial p}\frac{\partial T^*}{\partial p} + \frac{\mu_2}{a^2}\left(\frac{1}{\sin^2\vartheta}\frac{\partial T}{\partial\psi}\frac{\partial T^*}{\partial\psi} +\right.\right.$$

$$\left.\left. + \frac{\partial T}{\partial\vartheta}\frac{\partial T^*}{\partial\vartheta}\right)\right\} dD\, dt + \int\limits_{S_t} (u^* \sigma_\psi + v^* \sigma_\vartheta + \sigma T^* q_s)\Bigg|_{p=p_a} dS\, dt,$$

$$(\Lambda\varphi,\ \varphi^*) = \frac{1}{2}\left[\left(\frac{\partial\varphi}{\partial t}\varphi^* - \frac{\partial\varphi^*}{\partial t}\varphi\right) + (\varphi^* \vec{u} \operatorname{grad}\varphi - \varphi\vec{u} \operatorname{grad}\varphi^*),\right.$$

$$dD = dS\, dt, \quad dS = a^2 \sin\vartheta\, d\vartheta\, d\psi, \quad S_t = \{S \times [0,\ t]\},$$

$\vec{\varphi}^* = (u^*, v^*, T^*, \mu^*, \tau^*)$ is an arbitrary vector-function with sufficiently smooth components,

$$\vec{u}_s^* = (u^*,\ v^*),$$

σ is a dimensional factor selected in such a way that the summation operations make sense.

In classes of sufficiently smooth functions the representations of the model in the form of the system (7)-(16) with boundary and initial conditions and the integral identity (23) are equivalent. Substituting $\vec{\varphi}^* = \vec{\Phi}$ into (23), we obtain an equation for the balance of total energy of the system in the form

$$I(\vec{\varphi},\ \vec{Y},\ \vec{\varphi}) = 0. \tag{24}$$

The discretization of identity (23) is accomplished under the condition that the integrand retains its properties also in a discrete form. This condition guarantees energy balancing and a stability of discrete analogues of the model. The left-hand side in (23) has the structure of a scalar product and therefore in dependence on the form of representation of the vectors $\vec{\varphi}$, $\vec{\varphi}^*$, $\vec{Y}$ discretization is obtained by the spectral method, the finite elements method or the finite difference method. Henceforth for greater clarity we will employ the finite-difference form in which the vectors $\vec{\varphi}$, $\vec{\varphi}^*$, $\vec{Y}$ are determined in a narrow grid region $D_t^h \subset D_t$. In this case the method of model discretization is described in detail in [9].

Models of dynamics of the ocean and models of interaction between the atmosphere and ocean allow a similar variation formulation in the form of an integral identity of the same structure as in (23). The conditions at the water-air discontinuity and also the condition of equality to zero for the normal component of the velocity vector at the boundaries and conditions containing the derivatives of the vector of state components along the normal are natural for the variation functional. Use of the weak approximation method with fractional steps [2] for discretization of the identity in time leads to a family of energetically balanced splitting schemes.

Due to the diversity of the components of the vector of parameters it is convenient to number them in order, using a grid representation, and introduce the new notation

$$\vec{Y} = \{Y_i\,(i = \overline{1, N})\}, \tag{25}$$

where N is the total number of components, determined by the number of functions in $\vec{Y}$ different in sense and the number of points of intersection in the region D_t^h.

The set of admissible values of the parameters $R(D_t)$ is described on the basis of physical representations, a priori information and intuition, embodied in the mathematical model, and also on the basis of processing of the results of measurements in a real system. In stipulating the specific values $\vec{Y} \in R(D_t)$ for solving problem (1), in actuality we do not know the precise values of its components. Therefore, in the modeling process the problem arises of using the influence of variations of the input parameters on the state of the system or on refining the parameters on the basis of additional information on behavior of the modeled system. The first problem relates to the general problem of model sensitivity to variations of the input parameters and the second, to the general problem of identification of the parameters in accordance with the stipulated criterion.

We will characterize the behavior of the model by some functional which was defined above as the quality criterion. We will assume that this functional is continuous, limited and we will differentiate in the set of functions $\vec{\varphi} \in Q(D_t)$. If there are data on measurements of the vector of state, then this functional can be represented in the form

$$\Phi(\vec{\varphi}) = \| \vec{\varphi} - \vec{\varphi}_m \|_{D_t^m}, \tag{26}$$

where the norm determines the measure of deviation between the values of the vector of state measured and computed using the model.

Without reducing the form of the functional (26) to specific form, we note that it was determined in a specific set of points D_t^m at which measurements were made of the vector of state or some functions of its components. This means that for computing the values of the functional (26) in the model it is necessary to have procedures for transfer of the information from the regular grid region D_t^h into the irregular grid D_t^m and for modeling the measurement process. We will make an evaluation and adjustment of the $\vec{Y}$ parameters, using as a point of departure the conditions of minimizing of the functional $\Phi(\vec{\varphi})$ in a set of values of the parameters $R(D_t)$.

A choice of the functional in the form (26) is natural. It is convenient in diagnostic investigations of the model because it does not require differentiation of the measurement data. However, if the model is used in a forecasting regime, there are no measured values of the vector of state. In this case as the criterion we introduce some functional characterizing the behavior of the model as a whole, both in the region D_t and in $R(D_t)$.

Now we will set forth a scheme for an algorithm for evaluating the parameters, assuming that the form of the functional is determined by an explicit dependence on the components of the vector of state $\vec{\varphi}$. This algorithm realizes the relationship between changes in the vector $\vec{Y}$ and the functional $\Phi(\vec{\varphi})$.

For a study of the behavior of the model in parameter space $R(D_t)$ we will use the ideas of the most rapid descent method. In this space we will determine the metrics in the following way:

$$ds^2 = \sum_{i=1}^{N} \eta_i \, dY_i^2, \tag{27}$$

where dY_i is the change in the i-th component of the $\vec{Y}$ vector and η_i are scale factors selected in such a way that the summation operation in (27) makes sense.

The choice of scales is made on the basis of a priori information. The scale factors in (27) play more than a formal role. In optimization problems the rate of convergence of the most rapid descent method is dependent on them. The best choice is a choice of scales in which the functional level surfaces are close to spherical. Henceforth we will assume that the a priori information on the model will be adequate for normalizing the parameters to their characteristic values.

The change in the functional $\Phi(\vec{\varphi})$ in dependence on change in length is determined by the expression

$$\frac{d\Phi(\vec{\varphi})}{ds}=\sum_{i=1}^{N}\frac{\partial\Phi(\vec{\varphi})}{\partial Y_i}\frac{dY_i}{ds}. \tag{28}$$

The most rapid descent direction corresponds to the greatest negative value $d\Phi(\vec{\varphi})/ds$, which makes expression (28) stationary under the condition (27). These stationarity conditions lead to an equation for the rate of change in the parameter Y_i in the direction s

$$\frac{dY_i}{ds}=\pm\left[\sum_{i=1}^{N}\frac{1}{\gamma_{ii}}\left(\frac{\partial\Phi}{\partial Y_i}\right)^2\right]^{-1/2}\frac{1}{\gamma_{ii}}\frac{\partial\Phi(\vec{\varphi})}{\partial Y_i}\quad(i=\overline{1\ N}). \tag{29}$$

The plus sign in (29) corresponds to the rate of change in the parameters in the direction of the most rapid ascent, and the minus sign corresponds to the rate of change in the parameters in the direction of most rapid descent.

If the derivative ds/dt is identified with the rate of change of the model in parameter space, which we will denote by U_p, then it is possible to write the expression

$$\frac{dY_i}{dt}=\frac{\partial Y_i}{\partial s}\frac{ds}{dt}\equiv\frac{\partial Y_i}{\partial s}U_p\quad(i=\overline{1,\ N}). \tag{30}$$

Now, in order to obtain an expression for the rate of change in the parameter in the direction of most rapid descent in the form

$$\frac{dY_i}{dt}=-\left(\frac{k}{\gamma_{ii}}\right)\frac{\partial\Phi(\vec{\varphi})}{\partial Y_i}\quad(i=\overline{1,\ N}) \tag{31}$$

it is sufficient to select the rate U_p proportional to the modulus of the functional gradient in the direction of the vector of parameters, that is

$$U_p=k\left[\sum_{i=1}^{N}\frac{1}{\gamma_{ii}}\left(\frac{\partial\Phi}{\partial Y_i}\right)^2\right]^{1/2}, \tag{32}$$

where $k>0$ is a proportionality factor.

The difference analogue of equation (31) has the form

$$Y_i^{j+1}=Y_i^j-\left(\frac{k\Delta t}{\gamma_{ii}}\right)\frac{\partial\Phi}{\partial Y_i}\quad(i=\overline{1,\ N}), \tag{33}$$

where j is the number of the interval and Δt is the length of the interval in which the integration of the equations of the model in time occurs.

Thus, the hypothesis that the velocity of movement in parameter space is proportional to the vector modulus -- the gradient

$$\text{grad}_{\vec{Y}}\,\Phi(\vec{\varphi})$$

of the functional in the direction of the $\vec{Y}$ vector leads to a system of differential equations relating the changes in the parameters of the model with time and changes in the quality criterion.

For solving system (31) with use of the difference analogue (33) it is necessary in each time interval to compute the vector components

$$\mathrm{grad}_{\vec{Y}} \Phi(\vec{\varphi}) \equiv \left\{ \frac{\partial \Phi}{\partial Y_i} \ (i = \overline{1, N}) \right\}. \tag{34}$$

The algorithm for computing the components of this vector was described in [7]. Here we will describe it briefly. We will write expressions for variation of the functional $\Phi(\vec{\varphi})$, taking into account assumptions concerning its differentiability

$$\delta\Phi(\vec{\varphi}) = (\mathrm{grad}_{\vec{\varphi}} \Phi(\vec{\varphi}), \delta\vec{\varphi}), \tag{35}$$

$$\delta\Phi(\vec{\varphi}) = (\mathrm{grad}_{\vec{Y}} \Phi(\vec{\varphi}), \delta\vec{Y}), \tag{36}$$

where $\delta\vec{Y}$ is the variation of the vector of parameters and $\delta\vec{\varphi}$ is variation of the vector of state.

Variation in the form (35) is computed directly, since the functional $\Phi(\vec{\varphi})$ is assumed to be explicitly dependent on the vector of state. The functional in a general case is nonlinear. Considering it as a function of many variables, determined in a discrete set of points of intersection D_t^h or D_t^m, for computing (35) we obtain the following formulas:

$$\delta\Phi(\vec{\varphi}) = \lim_{\zeta\to 0} \frac{\partial}{\partial \zeta} \Phi^h(\vec{\varphi} + \zeta\delta\vec{\varphi}), \tag{37}$$

$$\mathrm{grad}_{\vec{\varphi}} \Phi = \frac{\partial}{\partial \delta\varphi} [\lim_{\zeta\to 0} \Phi^h(\vec{\varphi} + \zeta\delta\vec{\varphi})], \tag{38}$$

where ζ is a real parameter and the superscript h here and in the text which follows denotes a discrete analogue. The variations $\delta\vec{\varphi}$, $\delta\Phi(\vec{\varphi})$ and the vector $\mathrm{grad}_{\vec{\varphi}} \Phi$ are determined in the neighborhood of the known unperturbed value of the vector of state.

Equation (36) is the basic relationship of model sensitivity relative to variations of the input parameters if as the sensitivity (response) measure we use the functional $\Phi(\vec{\varphi})$. In essence, this equation determines the accuracy in computing the functional with stipulated errors of the vector of input parameters. The components of the vector $\mathrm{grad}_{\vec{Y}} \Phi$ are functions of model response. A knowledge of this vector makes it possible to relate the changes in the parameters and the quality functional. For computing the components of the vector $\mathrm{grad}_{\vec{Y}} \Phi$ we use the Lagrange factors method. Assume that variation of the functional and the vector $\mathrm{grad}_{\vec{Y}} \Phi$ are determined in the neighborhood of the unperturbed state satisfying the system of discrete equations (5). Then in place of the functional $\Phi(\vec{\varphi})$ it is possible to consider the equivalent functional

$$J_0(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*) = \Phi(\vec{\varphi}) + I(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*), \tag{39}$$

where $I(\vec{\varphi}, \vec{Y}, \vec{\varphi}^*)$ is determined by the left-hand side of the identity (3) and $\vec{\varphi}^*$ plays the role of the vector of Lagrange factors. If now the function $\vec{\varphi}^*$ is selected in such a way that it is the solution of the conjugate problem, which follows from the conditions of stationarity of the functional (39)

$$\frac{\partial}{\partial \delta \vec{\varphi}} \left[\lim_{\zeta \to 0} \frac{\partial}{\partial \zeta} I^h(\vec{\varphi} + \zeta \delta \vec{\varphi}, \vec{Y}, \vec{\varphi}) \right] + \mathrm{grad}_{\vec{\varphi}} \Phi^h(\vec{\varphi}) = 0, \quad \varphi^*(\bar{t}) = 0, \tag{40}$$

then the sought-for variation acquires the simplest form

$$\delta\Phi(\vec{\varphi}) = \lim_{\zeta \to 0} \frac{\partial}{\partial \zeta} I^h(\vec{\varphi}, \vec{Y} + \zeta \delta \vec{Y}, \vec{\varphi}^*), \tag{41}$$

and vector $\mathrm{grad}_{\vec{Y}} \Phi$ is computed using the formula

$$\mathrm{grad}_{\vec{Y}} \Phi = \frac{\partial}{\partial \delta \vec{Y}} \left[\lim_{\zeta \to 0} \frac{\partial}{\partial \zeta} I^h(\vec{\varphi}, \vec{Y} + \zeta \delta \vec{Y}, \vec{\varphi}^*) \right]. \tag{42}$$

Expression (41) determines the sequence of operations for computing the variations and simultaneously gives a determination of the scalar product in (36).

Thus, we have formulated an algorithm for computing the components of the vector $\mathrm{grad}_{\vec{Y}} \Phi$ for functionals of a general form. In order to close the cycle of computations using the difference equation (33) it is necessary to stipulate the proportionality factor k.

With availability of measured values of the vector of state there can be two methods for adjusting the parameters. In the first the adjustment is accomplished simultaneously in the entire interval $[0, \bar{t}]$. In this case we solve the problem of minimizing the functional (26) in the set of input parameters, with the limitations described by the system of equations (5). Equation (33), together with (5), (40) and (42) determines the iteration scheme in the most rapid descent method. The factor k, being here an iteration parameter, is selected from the condition of a minimum of the functional (26) in the direction of the vector $\vec{Y}^{j+1}$. The iterations are carried out until the convergence test is satisfied.

In the second variant of the adjustment scheme the entire procedure is considered in one time interval with the length Δt. This scheme is convenient in the case of a continuous assimilation of measurement data or in the case of continuous tracking of the model quality criterion. The algorithm for realization of this scheme is the same as for the entire interval, only the integral identity (3) and all the computation formulas are considered in each of the intervals $[t_j, t_{j+1}]$ in place of $[0, \bar{t}]$. With the availability of measurement data in each time interval we solve the problem of minimizing a functional of the type (26). The model in this case plays the role of a space-time interpolant, by means of which on the basis of measurement data and the minimizing condition there is restoration of the vector components in the entire region. When the model is used in a forecasting regime and no measurement data are available an adjustment of the parameters is made on the basis of variations of the quality criterion and the adjustment process itself can be without iterations.

Now we will write a scheme for an algorithm for the successive assimilation of data and evaluation of the parameters.

1) It is assumed that at the moment in time t_j there is stipulation of the values of the vector of state $\vec{\varphi}^j$, the vector of parameters Y^j and the functional $\Phi(\vec{\varphi}^j)$.

2) The problem (5) is solved in the interval $[t_j, t_{j+1}]$; as a result, we obtain the vector of state $\vec{\varphi}^{j+1}$, and from it we compute the value of the functional $\Phi(\varphi^{j+1})$.

3) The components of the vector $\text{grad}_{\vec{\varphi}} \Phi$ at the moment in time t_{j+1} are computed, and also the increment of the functional

$$\Delta\Phi^{j+1} = \Phi(\vec{\varphi}^{j+1}) - \Phi(\vec{\varphi}^j). \tag{43}$$

The functional $\Phi(\vec{\varphi})$ in a general case is nonlinear and therefore the increment (43) will differ somewhat from the variation computed using formula (37) with $\delta\vec{\varphi} = \vec{\varphi}^{j+1} - \vec{\varphi}^j$. However, taking into account that the time interval is quite small, this difference can be neglected.

4) In the interval $[t_j, t_{j+1}]$ we solve the conjugate problem (40) with the condition $\varphi^*(t_{j+1}) = 0$ and with a free term equal to $\text{grad}_{\vec{\varphi}} \Phi|_{t = t_{j+1}}$.

5) Using formulas (42) we compute the values of the components of the vector $\text{grad}_{\vec{Y}} \Phi$ at the moment in time t_j.

6) We determine the k factor from the condition of a minimum of the functional $\Phi(\vec{\varphi})$ with $t = t_{j+1}$ in the direction of the vector $\vec{Y}^{j+1}$. For determining k in solving forecasting problems it is possible to use the approximate equation

$$\Delta\Phi^{j+1} = \lim_{\zeta\to 0} \frac{\partial}{\partial\zeta} I^h(\vec{\varphi}, \vec{Y}^j + \zeta\Delta\vec{Y}^{j+1}, \vec{\varphi}^*). \tag{44}$$

where

$$\Delta\vec{Y}^{j+1} = \{\Delta Y_i\}, \quad \Delta Y_i = \frac{k}{\eta_i}\frac{\partial\Phi}{\partial Y_i}\Big|_{t=t_j} \quad (i = \overline{1, N}).$$

7) The new values of the parameters are computed using the formula

$$Y_i^{j+1} = Y_i^j + \Delta Y_i, \quad i = \overline{1, N}. \tag{45}$$

Equation (44) is linear relative to k and it is soluble if at least one of the components of the vector grad $_{\vec{Y}}\,\Phi$ is different from zero. If the increment $\Delta\Phi^{j+1}$ is greater than some stipulated value, computations of points 2-7 are repeated by iterations until attaining the convergence condition or the minimum of the functional $\Phi(\vec{\varphi})$ with $t = t_{j+1}$.

The described scheme makes it possible to carry out successive evaluation of the parameters and assimilation of data as they are received. If the interval of information receipt is small in comparison with the interval Δt and it is undesirable to decrease this interval, averaging of the measured information in the Δt interval is carried out.

For forecasting purposes the proposed method is implemented in the following way. First we stipulate the approximate values of the components of the vector $\vec{Y}$ and their refinement is carried out by minimizing functionals of the type (26) in the time interval preceding the predicted interval. An example of solution of this problem for a linearized model of atmospheric dynamics is described in [7]. If the model is used for forecasting, we select a quality criterion which is no longer dependent on measurement data. In the computation process we make an analysis of the behavior of this criterion and in case of necessity a scheme for adjusting the parameters is included.

The computation algorithm realizing the scheme for refining the parameters and assimilation of information is not dependent on the functional form. Accordingly, there is a possibility of experimentally checking the most suitable criterion. As an example, we will examine the functional determining the kinetic energy of the system. Assume that turbulence coefficients are among the parameters. The adjustment scheme will operate as a regulator. With an increase in kinetic energy, in accordance with the adjustment scheme there will be an increase in the values of the turbulence coefficients, and with a decrease in energy the coefficients also decrease. A change in the coefficients is determined by the function of sensitivity of the functional to variations of the adjustable parameters; each variation has its own influence region. The use of the discrete model (5), (40) as a spatial-temporal interpolant in the assimilation of measurement data is a constructive difference between the proposed algorithm and the Kalman filtering algorithm. [1]. The use of the weak approximation and splitting methods makes the realization scheme simple and economical.

It is obvious that the more a priori information is available concerning the model and the behavior of the parameters and the less it is necessary to evaluate the parameters, the more effective will be the operation of the adjustment scheme. Taking this into account, with stipulation of the parameters it is desirable to use the most complete models, giving a qualitatively correct description, and refinement and adjustment are carried out only for those parameters which are not determined unambiguously in these models.

Now we will examine the problem of the choice of an initial approximation for evaluating the parameters. For this purpose the method which is the simplest to apply is the so-called differential approximation method [2, 10], based on the idea of the least squares method. In accordance with this method it is assumed that there is complete information on the vector of state, adequate for computing all the derivatives of space variables and time in the system of equations (1). An evaluation of the vector of parameters $\vec{Y}$ is obtained from the condition of a minimum of the functional

$$\int_{D_t} \| B \frac{\partial \vec{\varphi}}{\partial t} + L(\vec{\varphi}, \vec{Y}) \|^2 \, \omega(\vec{x}, t) \, dD\,dt \qquad (46)$$

in the region of change in the parameters $R(\vec{Y})$. The norm in (46) is introduced in such a way as to take into account the difference in the dimensionalities of the components of the vector $\vec{\varphi}$, whereas $\omega(\vec{x}, t)$ is a nonnegative weighting function satisfying the normalization condition

$$\int_{D_t} \omega(\vec{x}, t) \, dD\,dt = 1. \qquad (47)$$

The choice of the weighting function is made on the basis of a priori information on the model and errors in measuring the components of the vector of state. It is possible to introduce the norms and weighting function in such a way as to take into account a priori information on each of the equations of the system (1). The discretization of the integral in (46) is accomplished the same as in the integral identity (4), and for approximation of the integrand we use the system of difference equations (5).

If the operator $L(\vec{\varphi}, \vec{Y})$ is linearly dependent on the $\vec{Y}$ vector, the conditions of minimum of the functional (46) lead to a linear system of algebraic equations relative to the components of the vector $\vec{Y}$, whose solution gives a necessary evaluation of the initial values of the parameters.

Now we will note some peculiarities of the differential approximation method. Its simplicity, even with the small dimensionality of the vector of parameters, is apparent for the considered class of problems in the modeling of the atmosphere and ocean. The fact is that the existing system of measurements in the atmosphere, especially over the ocean, and in the ocean, does not give complete and reliable information necessary for application of this method. Therefore, it is necessary to make some assumptions concerning its applicability. In addition, although the least squares method also ensures some smoothing, the differentiation of the components of the vector of state obtained as a result of processing of measurement data intensifies the influence of different kinds of noise, and this, in turn, makes it difficult to obtain unbiased evaluations for the parameters.

This means that great caution must be exercised in use of the differential approximation method for a diagnostic analysis of models of dynamics of the atmosphere and ocean and applying the conclusions drawn on its basis.

However, as a method for obtaining an initial approximation for evaluations of parameters it is extremely attractive as a result of the simplicity of its application on computers.

Identification of the parameters of discrete models is one of the aspects of the problem of numerical modeling of dynamics of the atmosphere and ocean. The following base elements determine the overall structure of numerical models for each class of problems:
-- the system of fundamental equations (1) and the integral identity (3), their discrete analogues (5) and (4) and computation algorithms for realizing the transformation (2);
-- the system of conjugate equations (6) and algorithms for its realization;
-- the algorithms for investigating the response of the models to variations of the input parameters and for evaluating the accuracy of solution of the problem with stipulated errors in the input parameters;
-- the algorithms for identification of parameters on the basis of factual information and a stipulated criterion.

All these elements are closely related to one another. The principal connecting link, from the algorithmic point of view, is the variation principle, which not only simplifies the process of constructing discrete models, but also makes it possible to apply new methods to the problem of numerical modeling and in fuller form use experimental information on the object being modeled.

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PARAMETERIZATION OF THE ICE COVER IN GLOBAL MODELS OF INTERACTION BETWEEN THE OCEAN AND THE ATMOSPHERE

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[Article by M. Yu. Belevich, Institute of Oceanology USSR Academy of Sciences, submitted for publication 31 October 1978]

Abstract: The author examines a model of sea ice within the framework of a model of general circulation of the atmosphere and ocean. Simple formulas are proposed for computing ice thickness and the temperature of its surface, taking into account the thermodynamics of the processes of growth and melting of the ice. Generalizations are given for the case of ice covered by snow and an allowance is made for advection of ice by sea currents.

[Text] In the numerical modeling of interaction between the ocean and the atmosphere the need arises for taking into account the ice cover in the high latitudes. The method employed up to this time in the Institute of Oceanology model [2] had the shortcoming that it did not take into account the ice thickness: with a decrease in the temperature of the ocean surface to 271.2K (the mean freezing temperature of sea water) the ocean was considered to be covered with ice, whereas with an increase in the temperature of the ice surface to 273.2K (melting temperature of fresh ice) it was assumed that the ice disappears. A more precise parameterization of the ice cover was used in the Bryan model of general circulation of the ocean [1]. He postulated that ice does not have thermal inertia (the heat capacity of ice, in other words, is equal to zero), so that the vertical transfer of heat locally could be described by the stationary heat conductivity equation

$$\frac{\partial^2 T}{\partial z^2} = 0, \tag{1}$$

(T is temperature, z is the vertical coordinate, normal to the ice surface). This supposition is satisfied satisfactorily only for relatively thin ice. In actuality, from the nonstationary heat conductivity equation

$$\frac{\partial T}{\partial t}=\chi\frac{\partial^2 T}{\partial z^2} \tag{2}$$

(t is time, χ is the thermal conductivity coefficient) we have the evaluation

$$\Delta t\sim H^2/\chi,$$

where H is the characteristic thickness of the ice, $\chi \approx 10^{-6}$ m^2/sec. Thus, if the objective is to describe variations in ice thickness with a period not less than a day ($\Delta t \approx 10^5$ sec), equation (1) is correct only for relatively thin ice ($H \approx 0.3$ m).

In the method for parameterization of processes of growth and melting of ice proposed below an attempt is made to avoid these shortcomings.

A model of ice as a "block" in a global model of interaction between the ocean and the atmosphere is necessary for the correct computation of the temperature of the ocean surface T_s, covered by ice with the thickness H. As a simplification of the problem we will assume that:
-- the ice is fresh, homogeneous with the density ρ = const;
-- solid precipitation is not considered;
-- the water forming during melting at the ice-air discontinuity and the liquid precipitation instantaneously penetrate through the ice layer;
-- the thermophysical characteristics of the ice -- the coefficients of heat conductivity λ, thermal conductivity χ, specific heat of fusion L, temperature of ice formation T_F and melting T_M are considered constant.

With the assumptions made the heat transfer process in the ice is described by the one-dimensional heat conductivity equation (2). The regimes of growth and melting of ice are substantially different from one another and therefore we will examine them separately.

The following boundary conditions are set at the upper and lower boundaries in a growth regime:

$$T|_{z=H}=T_F, \tag{3}$$

$$\left.\frac{\partial T}{\partial z}\right|_{z=0}=-\frac{Q}{\lambda}, \tag{4}$$

where Q is the heat flow at the ice-air discontinuity.

We will make one other assumption, to wit: we will neglect the temporal change in the functions Q and H and we will assume them to be equal to Q_0 and H_0 (values at a time t = 0). Now we will estimate the time scale of ice growth. From the heat balance equation at the lower boundary we have

$$t_H\sim\frac{H^2 L\rho}{\lambda\Delta T}.$$

However, the heat conductivity scale is

$$t_T\sim\frac{H^2}{\chi}.$$

Since $t_T/t_H \sim 10^{-2} \ll 1$, the assumption made of a quasistationary nature of H does not introduce major errors. Such an assumption, correct for small t, makes it possible to avoid solutions of the nonlinear Stefan problem. We note in passing that in the case of appearance of inadmissibly high changes in Q and H within the limits of one time interval they can be taken into account by the organization of an entirely obvious iteration procedure.

We will seek solution of the problem (2)-(4) in the form

$$T(z, t) = az + b + \sum_{n=1}^{\infty} c_n e^{-k^2 n^2 \chi t} \sin kn (H_0 - z) \tag{5}$$

(a, b, c_n, k are constants). Here and in the text which follows we will neglect the contribution of harmonics with $n \geqslant 2$, then

$$T(z, t) = az + b + ce^{-k^2 \chi t} \sin k(H_0 - z). \tag{6}$$

This expression obviously satisfies equation (2). Substituting (6) into the boundary conditions, we obtain two equations for determining the unknown constants:

$$aH_0 + b = T_F, \tag{7}$$

$$a - kce^{-k^2 \chi t} \cos kH_0 = -\frac{Q_0}{\lambda}. \tag{8}$$

The third lacking equation is derived from the initial condition $T|_{\substack{z=0\\t=0}} = T_{s0}$:

$$b + c \sin k H_0 = T_{s0}. \tag{9}$$

It necessarily follows from equation (8) that

$$k = \frac{\pi}{2H_0}, \tag{10}$$

$$a = -\frac{Q_0}{\lambda} \tag{11}$$

In this case from (7) we have

$$b = T_F + \frac{Q_0 H_0}{\lambda}, \tag{12}$$

and from (9)

$$c = T_{s0} - T_F - \frac{Q_0 H_0}{\lambda}. \tag{13}$$

Thus, the sought-for surface temperature of ice is expressed as follows:

$$T_s = \left(T_F + \frac{Q_0 H_0}{\lambda}\right) + \left(T_{s0} - \left(T_F + \frac{Q_0 H_0}{\lambda}\right)\right) e^{-k^2 \chi t}. \tag{14}$$

The evolution of ice thickness is described by the following Cauchy problem:

$$\frac{dH}{dt} = \frac{\lambda}{L\rho}\left(\frac{B}{\lambda} + \left.\frac{\partial T}{\partial z}\right|_{z=H}\right), \tag{15}$$

$$H|_{t=0} = H_0, \tag{16}$$

where B is the heat flow from the water to the ice.

Equation (15) is the heat balance equation at the moving ice-water discontinuity. Substituting

$$\left.\frac{\partial T}{\partial z}\right|_{z=H_0} = -cke^{-k^2\chi t} - \frac{Q_0}{\lambda} \tag{17}$$

into (15) and integrating from C to t, we obtain

$$H = H_0 + \frac{B_0 - Q_0}{L\rho}t - \frac{c\lambda}{k\chi L\rho}(1 - e^{-k^2\chi t}). \tag{18}$$

In the integration here we made the same assumptions with respect to B as were made with respect to H and Q.

A specific characteristic of the ice melting regime is that with the assumptions made we have two moving discontinuities: ice-water discontinuity (moves with the velocity dH_1/dt) and ice-air discontinuity (moves with the velocity dH_2/dt). In this case at the upper boundary we set the condition

$$T(H_2, t) = T_M, \tag{19}$$

and at the lower boundary we leave the condition (3).

The heat balance conditions at the upper and lower boundaries are written as follows:

$$\frac{dH_2}{dt} = \frac{\lambda}{L\rho}\left(\frac{Q}{\lambda} + \left.\frac{\partial T}{\partial z}\right|_{z=H_2}\right), \tag{20}$$

$$\frac{dH_1}{dt} = \frac{\lambda}{L\rho}\left(\frac{B}{\lambda} + \left.\frac{\partial T}{\partial z}\right|_{z=H_1}\right). \tag{21}$$

If, as before, we denote the ice thickness by H, that is

$$H = H_1 - H_2, \tag{22}$$

then the conditions (20) and (21) can be written together:

$$\frac{dH}{dt} = \frac{\lambda}{L\rho}\left(\frac{B-Q}{\lambda} + \left.\frac{\partial T}{\partial z}\right|_{z=H_2}^{z=H_1}\right). \tag{23}$$

With respect to the functions Q, B, H_1 and H_2 we will make assumptions similar to those adopted above.

We will seek a solution in the form

$$T(z, t) = az + b + ce^{-k^2\chi t}\sin k(H_{10} - z). \tag{24}$$

Substituting (24) into the boundary conditions (3) and (19), we obtain:

$$aH_{10} + b = T_F, \tag{25}$$

$$aH_{20} + b + ce^{-k^2 \chi t} \sin kH_0 = T_M. \tag{26}$$

For satisfaction of equation (26) it is necessary that

$$k = \frac{\pi}{H_0}. \tag{27}$$

Solving the system (25), (26), with (27) taken into account, we find

$$a = -\frac{T_M - T_F}{H_0}, \quad b = \frac{H_{10} T_M - H_{20} T_F}{H_0}. \tag{28}$$

Differentiating (24) for t and substituting the derivative with known a, b and k into (23), we obtain the equation for evolution of H:

$$\frac{dH}{dt} = \frac{\lambda}{L\rho}\left(\frac{B_0 - Q_0}{\lambda} - 2\,cke^{-k^2 \chi t}\right). \tag{29}$$

The unknown coefficient c can be found if $\left.\frac{dH}{dt}\right|_{t=0} = H'_{t0}$;

is stipulated. Then

$$c = -\frac{1}{2k\lambda}(Q_0 - B_0 - L\rho H'_{t0}). \tag{30}$$

The result of integration of (29) with time will be

$$H = H_0 - \frac{\lambda}{L\rho}\left(\frac{Q_0 - B_0}{\lambda}\, t + \frac{2c}{k\chi}\left(1 - e^{-k^2 \chi t}\right)\right). \tag{31}$$

The developed local model can be generalized for two important cases. We will generalize the model for the case of falling of snow. The origin of coordinates is placed at the ice-snow discontinuity. We will assume that snow with the thickness η has constant thermophysical parameters. We will also assume that η changes little in the neighborhood t = 0 and is equal to $\eta_0 = \eta|_{t=0}$. The processes in the snow-ice system will be described by the nonstationary equation (2), but now

$$\chi = \begin{cases} \chi_i, & z \in [0,\ H] \\ \chi_{sn}, & z \in [-\eta,\ 0) \end{cases} \tag{32}$$

(subscripts: i — ice, sn -- snow). We will use T_S to denote the temperature of the snow surface. At the ice-snow boundary there must be satisfaction of the conjugation equations

$$T_i(0,\ t) = T_{sn}(0,\ t), \tag{33}$$

$$\lambda_i \left.\frac{\partial T_i}{\partial z}\right|_{z=0} = \lambda_{sn} \left.\frac{\partial T_{sn}}{\partial z}\right|_{z=0}. \tag{34}$$

Here it is also possible to discriminate two regimes: growth of ice and melting of ice and snow. Changes in the thickness of the snow cover $\eta(t)$, like of the derivative $d\eta/dt$, being the external parameters of the problem, in the case of an increase in η must be stipulated. In the case of melting the situation is different and a formula for computing $\eta(t)$ can be derived from the heat balance condition at the snow-air discontinuity. As before, we will examine both regimes separately.

a) In a growth regime we will substitute not only (33) and (34), but also the following boundary conditions:

$$\frac{\partial T}{\partial z}\Big|_{z=-\eta_0} = -\frac{Q_0}{\lambda_l}, \tag{35}$$

$$T|_{z=H_0} = T_F. \tag{36}$$

The solution is sought in the form

$$T_{sn}(z, t) = a_{sn} z + b_{sn} + c_{sn} e^{-k_{sn}^2 \chi_{sn} t} \sin k_{sn}(z + d_{sn}), \quad z<0, \tag{37}$$

$$T_l(z, t) = a_l z + b_l + c_l e^{-k_l^2 \chi_l t} \sin k_l (H_0 - z), \quad z \geqslant 0. \tag{38}$$

Substituting (37) and (38) into the boundary conditions (33)-(36) and the initial conditions

$$T_l(0, 0) = T_{l0}, \quad T_{sn}(-\eta_0, 0) = T_{s0}, \tag{39}$$

we obtain a system of equations for determining the unknown constants:

$$a_l H_0 + b_l = T_F, \tag{40}$$

$$a_{sn} + c_{sn} k_{sn} e^{-k_{sn}^2 \chi_{sn} t} \cos k_{sn} (d_{sn} - \eta_0) = -\frac{Q_0}{\lambda_{sn}}, \tag{41}$$

$$\lambda_{sn} a_{sn} + \lambda_{sn} c_{sn} k_{sn} \cos k_{sn} d_{sn} = \lambda_l a_l - \lambda_l k_l c_l \cos k_l H_0, \tag{42}$$

$$b_{sn} + c_{sn} e^{-k_{sn}^2 \chi_{sn} t} \sin k_{sn} d_{sn} = b_l + c_l e^{-k_l^2 \chi_l t} \sin k_l H_0, \tag{43}$$

$$b_l + c_l \sin k_l d_l = T_{l0}, \tag{44}$$

$$-a_{sn}\eta_0 + b_{sn} + c_{sn} \sin k_{sn} (d_{sn} - \eta_0) = T_{s0}. \tag{45}$$

It follows from equations (43) and (41) that

$$k_l = \frac{\pi}{H_0}, \quad k_{sn} = \frac{\pi}{2\eta_0}. \tag{46}$$

Then it is easy to find

$$d_{sn} = 2\eta_0, \tag{47}$$

$$a_{sn} = -\frac{Q_0}{\lambda_{sn}}, \tag{48}$$

$$b_{sn} = b_l = T_{l0}, \tag{49}$$

$$c_{sn} = T_{s0} - T_{l0} - \frac{Q_0 \eta_0}{\lambda_{sn}}, \tag{50}$$

$$a_l = (T_F - T_{l0})/H_0, \tag{51}$$

$$c_l = \frac{1}{\lambda_l k_l}(\lambda_{sn} a_{sn} - \lambda_l a_l - \lambda_{sn} c_{sn} k_{sn}). \tag{52}$$

The equation for evolution of ice thickness, evidently, is similar to (18):

$$H = H_0 + \frac{B_0 - Q_0}{L_i \rho_i} t - \frac{c_i \lambda_i}{k_i \chi_i L_i \rho_i} (1 - e^{-k_i^2 \chi_i t}). \tag{53}$$

b) In a melting regime at the snow-air discontinuity we have the condition

$$T(-\eta_0, 0) = T_M. \tag{54}$$

We will also seek a solution in the form (37), (38). At the discontinuity $z = -\eta_0$ we will write the heat balance condition

$$\lambda_{sn} \frac{\partial T_{sn}}{\partial z}\Big|_{z=-\eta_0} = -L_{sn} \rho_{sn} \frac{d\eta}{dt} - Q_0. \tag{55}$$

The system of equations relative to the unknown coefficients, obtained by substitution of the solution into (33), (34), (36), (39) and (54), has the form

$$a_i H_0 + b_i = T_F, \tag{56}$$

$$-a_{sn} \eta_0 + b_{sn} + c_{sn} e^{-k_{sn}^2 \chi_{sn} t} \sin k_{sn} (d_{sn} - \eta_0) = T_M, \tag{57}$$

$$\lambda_{sn} a_{sn} + \lambda_{sn} c_{sn} k_{sn} \cos k_{sn} d_{sn} = \lambda_i a_i - \lambda_i k_i c_i \cos k_i H_0, \tag{58}$$

$$b_{sn} + c_{sn} e^{-k_{sn}^2 \chi_{sn} t} \sin k_{sn} d_{sn} = b_i + c_i e^{-k_i^2 \chi_i t} \sin k_i H_0. \tag{59}$$

From (56)-(59) we find the values of the coefficients:

$$k_{sn} = \frac{\pi}{\eta_0}, \quad k_i = \frac{\pi}{H_0}, \tag{60}$$

$$a_i = \frac{T_F - T_{10}}{H_0}, \tag{61}$$

$$a_{sn} = \frac{T_{10} - T_M}{\eta_0}, \tag{62}$$

$$b_{sn} = b_i = T_{10}, \tag{63}$$

$$c_i = \frac{1}{\lambda_i k_i} (\lambda_{sn} a_{sn} - \lambda_i a_i - \lambda_{sn} c_{sn} k_{sn}). \tag{64}$$

For determining c_{sn} it is necessary to stipulate $\frac{d\eta}{dt}\Big|_{t=0} = \eta'_{t_0}$.

In this case

$$c_{sn} = \frac{1}{k_{sn}} \left(\frac{T_{10} - T_M}{\eta_0} + \frac{1}{\lambda_{sn}} (Q_0 - L_{sn} \rho_{sn} \eta'_{t_0}) \right). \tag{65}$$

The ice thickness is found using formula (53), and for η we obtain the equation

$$\eta = \eta_0 + \frac{\lambda_{sn}}{L_{sn} \rho_{sn}} \left(\left(\frac{Q_0}{\lambda_{sn}} + a_{sn} \right) t + \frac{c_{sn}}{k_{sn} \chi_{sn}} \left(1 - e^{-k_{sn}^2 \chi_{sn} t} \right) \right). \tag{66}$$

The second possible generalization relates to allowance for advection and horizontal diffusion of ice. It can be accomplished using the recommendations of Bryan [1].

We will assume that the advection of thin sea ice ($H < H_{cr}$, H_{cr} is the critical thickness of the ice) occurs with the mean velocity of currents in the upper layer of the ocean. When $H \gg H_{cr}$ we assume that movement as a result of large-scale advection is absent. We will also assume that horizontal mixing occurs as a result of turbulent diffusion, which has the same intensity as the turbulent diffusion of density. We will denote the horizontal velocity vector by $V = (u, v)$, K_h is the coefficient of horizontal turbulent exchange, $\delta H/\delta t$ is the local change in ice thickness; then

$$\frac{\partial H}{\partial t} = -\nabla(\delta_1 \mathbf{V} H) + K_h \Delta H + \frac{\delta H}{\delta t}, \tag{67}$$

where

$$\delta_1 = \begin{cases} 1, & H < H_{\text{кр}} \\ 0, & H > H_{\text{кр}}. \end{cases} \tag{68}$$

The same for the case of ice with snow is written in the form

$$\frac{\partial (H+\eta)}{\partial t} = -\nabla(\delta_1 \mathbf{V}(H+\eta)) + K_h \Delta (H+\eta) + \frac{\delta (H+\eta)}{\delta t}. \tag{69}$$

In formulas (67), (69) Δ is the Laplace operator on a sphere; the first term on the right-hand side describes the change in ice thickness (ice with snow) caused by horizontal advection, and the second describes the change as a result of horizontal diffusion.

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SOME PATTERNS OF INTERNAL CURRENTS OF LINEAR WATER FLOWS

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[Article by Candidate of Technical Sciences V. D. Ivanov, Irkutsk Scientific Research Institute of Precious and Nonferrous Metals, submitted for publication 30 October 1978]

Abstract: The article sets forth the results of generalization of preceding investigations and the author's experiments for ascertaining the patterns of internal currents in a linear water flow. The author has determined the dependence of the parameters of internal currents on the Froude and Reynolds numbers. It is demonstrated that there is a "division" of internal currents with an increase in Reynolds numbers and a decrease in their size with an increase in the Froude number. A classification of internal currents is proposed.

[Text] It is known that in linear water flows there is formation of helical internal currents [3-5]. An analysis of data in the literature shows that for the time being there is still no clear classification of a wide range of observed internal currents. This is holding back the drawing of the most important conclusions from work already done and is slowing down further study of this problem. The four types of internal currents given by Losiyevskiy are without question of interest, but they can make no pretense to a general approach in the study of internal currents. Therefore, it is no accident that their author drew only partial conclusions. L. D. Kozyrenko [3] examines the structure of internal currents, taking into account the Reynolds number and the ratio of trough width to the depth of flow. Whereas the first criterion characterizes the water flow regime, the second is not universal to the same degree.

The structure of internal currents must be considered more correctly from the point of view of the Reynolds and Froude numbers, as this is done in an evaluation of a water flow as a whole [6]. This also makes it possible to take into account both the regime and state (kinetic properties) of the flow. The results of the preceding investigations and those made by the author of this article were examined in accordance with Table 1.

Table 1

Classification of Internal Currents

Состояние 1	2 Режим			
	ламинарный 3	I переходный 4	II переходный 5	турбулентный 6
7 Спокойное, $Fr<1$	1	2	3	4
8 Критическое, $Fr=1$	5	6	7	8
9 Бурное, $Fr>1$	9	10	11	12

KEY:

1. State
2. Regime
3. Laminar
4. Transient I
5. Transient II
6. Turbulent
7. Calm
8. Critical
9. Turbulent

The transient regime was divided into two parts (transient I, Re = 300-1000, transient II, Re = 1000-3400. The arbitrary division is attributable to the fact that within these limits of Reynolds numbers the laws of motion of a fluid are not identical. Therefore, the division of the transient regime into at least two parts brings us closer to a more real understanding of the internal structure of water flows. The most thorough investigations of A. I. Losiyevskiy [4], L. D. Kozyrenko [3], Ye. M. Minskiy [5] according to this classification relate to calm flows (Table 1, boxes 1-4).

From this point of view the author gave an evaluation of the work of A. I. Losiyevskiy, carried out investigations for the detection of secondary currents (boxes 1-12) and attempted to obtain some general dependences of the parameters of internal currents on the Reynolds and Froude numbers.

The experimental conditions were prepared in such a way that in the horizontal boxes there were constant Froude numbers and the Reynolds numbers were increased in accordance with the flow regime. For the water flows corresponding to the vertical boxes (for example 1, 5, 9) the Reynolds numbers remain constant, whereas the Froude numbers increase from less than unity to a value greater than unity.

In the experiments we used a steel rectangular trough with a width of 85 mm, a height of 50 mm and a length of 4000 mm. Its working surface was covered with epoxy resin, had a smooth appearance and was wetted with water.

Table 2

Results of Investigations of Internal Currents of Linear Water Flows

Пара-метр 1	2 Состояние: бурное 3	критическое 4	спокойное 5	Пара-метр 1	2 Состояние: бурное 3	критическое 4	спокойное 5
6 *Ламинарный режим*				8 *II переходный режим*			
Fr	4,5	1,0	0,12	Fr	4,2	1,0	0,12
Re	180	183	180	Re	1800	1790	1820
H	0,09	0,15	0,3	*H*	0,43	0,69	1,4
V	20,0	12,2	6,0	*V*	42,0	26,0	13,0
a/b	2,2	1,9	2,0	*a/b*	0,91	0,72	0,86
2*a*	0,2	0,2—0,25	0,5—0,7	2*a*	0,2	0,25	0,5—0,6
S	0,014	0,031	0,16	*S*	0,035	0,073	0,33
7 *I переходный режим*				9 *Турбулентный режим*			
Fr	4,2	1,0	0,12	Fr	5,0	1,0	0,11
Re	660	670	630	Re	7000	6800	7500
H	0,22	0,37	0,7	*H*	1,0	1,7	3,5
V	30,0	18,0	9,0	*V*	70,0	40,0	20,0
a/b	0,91	0,72	0,86	*a/b*	1,0	0,71	0,86
2*a*	0,2	0,2—0,3	0,5—0,7	2*a*	0,2	0,25	0,5—0,7
S	0,035	0,073	0,33	*S*	0,035	0,073	0,33

KEY:

1. Parameter
2. State
3. Turbulent
4. Critical
5. Calm
6. Laminar regime
7. Transient regime I
8. Transient regime II
9. Turbulent regime

Note. The depth H is in cm; the velocity V is in cm/sec; the cross-sectional area of one internal current S is in cm^2; a and b are the horizontal and vertical semiaxes of the cross section of the internal flow in cm.

Prior to release of water into the trough its segment at the end with an area of about 100 cm^2 was covered by a dark water paint. After release of the water the paint was washed away and formed near the bottom in the form of bands. The latter were parallel to one another and to the trough. It was assumed that the reason for formation of the bands was internal currents, each of which washed away the paint beneath it, gradually concentrating it in the places of contact of adjacent internal currents. It was assumed that the paint (band) between currents diverging along the bottom disappeared more rapidly than the bands between the convergent currents. Therefore, the horizontal dimension of the cross section of the internal currents 2a was taken from the closest paint bands. In a number of cases with a relatively small trough slope and water flow velocity we used grains of potassium manganate which ensured clearly visible colored bands. The distance between the bands was registered using a ruler directly in the trough; the external appearance of the bands was photographed.

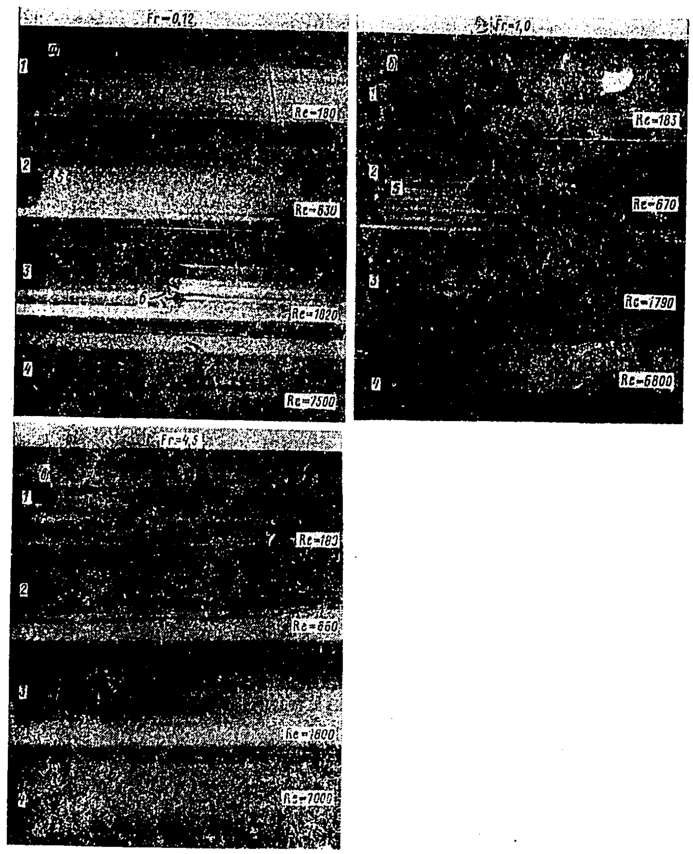

Fig. 1. Calm flows (a), flows with critical state (b) and turbulent flows (c). 1) laminar regime, 2) first transient, 3) second transient, 4) turbulent regime; 5) water paint, 6) grains of potassium manganate

The vertical semiaxis b or dimension 2b of the cross section of the internal current were not measured experimentally; their values were adopted on the basis of the following considerations. Some of the experiments were carried out by the author using fine water flows in which the depth H was less than the horizontal dimension of the cross section of the internal currents 2a or equal to it. Their only possible configuration could be an ellipse with a horizontal semimajor axis or in the form of a circle. And therefore in these cases it was assumed that the movement of internal currents was single-layered and 2b = H. In order to confirm this, large crystals of potassium manganate were introduced into a fine water flow; these marked the single-layer structure of the internal currents. This is also confirmed by the investigations of Losiyevskiy, who experimentally determined the 2b value in a linear water flow. Determination of the 2b value when H > 2a is described below.

Table 3

Parameters of Internal Currents According to Data from A. I. Losiyevskiy (Calm State)

Параметр (1)	Значения параметров (2)									Среднее (3)
					Ламинарный режим (4)					
Fr		0,090	0,03			0,01				
Re		208	75			192				
H		0,4	0,3			0.8				
V		6,0	3,0			3,0				
a/b		32,5	43			16,3				31
S		4,1	3,0			8,1				5,1
					5 *I переходный режим*					
Fr	0,24		0,045	0,021			0,0065	0,003	0,0022	
Re	609		428	813			332	640	806	
H	0,6		0,8	1,7			1,4	3,0	4,0	
V	12,0		6,0	6,0			3,0	3,0	3,0	
a/b	21,7		16,3	7,6			9,3	4,3	3,3	10
S	6,1		8,1	17,3			14,3	30,5	40,7	19,7
					6 *II переходный режим*					
Fr	0,14	0,070	0,041	0,014	0.01	0,012	0,008	0,005	0,00076	
Re	1037	2050	3200	1130	1420	1343	1840	2498	1686	
H	1,0	2,1	3,5	6,3	8,7	3,0	4,4	6,8	11,8	
V	12,0	12,0	12,0	3.0	3.0	6,0	6,0	6,0	3,0	
a/b	13	6,2	1,9	1,0	1,5	4,3	1,5	1,0	1,1	3,5
S	10,2	21,4	17,0	32,0	88,0	30,5	22,1	34,6	119	41,6
					7 *Турбулентный режим*					
Fr			0,03	0,019		0.014		0,003		
Re			4120	5567		6660		3663		
H			5,0	7,6		10,3		12,8		
V			12,0	12,0		12,0		6,0		
a/b			1,3	0,95		1,3		1,0		1,1
S			25	38		104		132		74,7

KEY:
1. Parameter
2. Values of parameters
3. Mean
4. Laminar regime
5. Transient regime I
6. Transient regime II
7. Turbulent regime

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The results of the investigation are presented in Table 2 and in Fig. 1 (in the case of large Reynolds numbers the photographs of the tracks were for technical reasons inadequately clear; individual curvatures of the tracks are attributable to local nonwettability of the trough bottom). The results of the work of Losiyevskiy, taking into account the classification of internal currents proposed by the author of this article, are given in Table 3. It can be seen from the latter table that the cross-sectional form of the internal currents is dependent on the water flow regime. As an average for calm laminar flows the ratio of the greater to the lesser semiaxis is equal to 31. With an increase in the Reynolds number this ratio decreases progressively to 10, 3.5 and 1.1. The elliptical form of the cross section of internal currents corresponds to laminar and transient regimes and the form of a circle corresponds to a turbulent-calm flow. In its investigation we used only "calm" flows with single-layer movement of internal currents (2b = H).

As a result of processing of the data in Table 3 it was established for the first time that the cross-sectional area of the internal currents in "calm" flows is simultaneously dependent on the Re and Fr numbers.

$$S = 0{,}017 \sqrt[3]{\left(\frac{\mathrm{Re}}{\mathrm{Fr}}\right)^2}.$$

With an increase in the Froude numbers the cross-sectional area of the internal currents decreases, whereas with an increase in the Reynolds number it increases.

The direction of rotation of the internal currents at the bottom of the trough is divergent for water flows with laminar and transient I regimes. The internal currents of water flows with a transient II regime are characterized by both convergent and divergent bottom flows. Turbulent flows (according to data from Losiyevskiy) correspond to secondary currents convergent at the bottom.

Laminar calm (close to critical), critical and turbulent flows with Re = const are characterized by a constancy of the ratio a/b, which in this case is equal to approximately 2 and is not dependent on the Froude number.

The more kinetic is a water flow with a constant value of the Reynolds number, the lesser is the cross section of the internal currents. Flows with the first transient regimes with $\mathrm{Fr} \geqslant 0.12$ are characterized by a configuration of the cross section of internal currents in the form of a circle. This configuration is retained in the range of calm flows (Fr = 0.12-1), in the case of a critical state (Fr = 1) and in the case of turbulent flows ($\mathrm{Fr} > 1$).

When the water flow regime is transient II, with Froude numbers relatively close to critical (beginning with Fr = 0.12), it becomes more difficult to evaluate the a/b ratio. Only one thing is clear, that with a constancy of the value of the Froude number and a change in the Reynolds number the value 2a = const (demonstrated by the author's experiments, Table 2). In this case the 2b value is unknown. We will assume that the ratio a/b here is the same as in transient regime I; then it is found that $2b \approx H/2$ and an internal current is observed only in the lower half of the water flow. This is improbable, in more likelihood internal currents occupy the entire cross section of the water flow [3-5]. Then 2b = H and each internal current has a/b ≈ 0.5 and the greater axis of the ellipse is directed from the bottom to the surface of the flow. In this case doubt naturally arises as to the stability of such internal currents when there is a great velocity gradient with depth. Therefore, such internal currents must be divided with retention of the 2a value.

What will be the configuration of the cross sections of internal currents in this case? An elliptical form is characteristic (not taking into account water flows with small Froude numbers, $Fr < 0.12$) for laminar flows with any state. With an increase in the Reynolds numbers (transient regime I) internal currents in form approach a circle. Therefore, it is most probable that this form is also retained for transient regime II. Then with $Re \approx 1800$ (Table 2) the water flows must move in two layers of internal currents. The very same thing applies to water flows with transient regime II, critical and turbulent states.

Table 4

Evaluation of Kinetic Energy of Internal Currents of Water Flow in Trough With a Width of 85 mm and a Length of 2,400 mm

Угол накло-на желоба (1)	H см	V см/сек (2)	a см	b см	abV^2
(3) Расход водного потока 220 см³/сек					
0°10′	1,5	17,5	1,05	0,75	230
1 45	0,6	43,6	0,35	0,30	200
5 40	0,4	65,2	0,30	0,20	250
(4) Расход водного потока 400 см³/сек					
0 10	2,8	16,7	1,4	1,4	550
1 45	1,0	46,0	0,50	0,50	530
5 40	0,6	78,6	0,30	0,30	550

KEY:

1. Angle of trough slope
2. cm/sec
3. Discharge of water flow 220 cm^3/sec
4. Discharge of water flow 400 cm^3/sec

The most numerous flows in nature and engineering are turbulent flows. With Fr = 0.01-0.013 and Re = $(1-3)\cdot 10^6$, according to the experimental data of Ye. M. Minskiy, the a/b ratio varies in the range 22-40. With values Fr = 0.003-0.03 and Re = 3600-4100 (Losiyevskiy experiments) and with $Fr \geqslant 1$ and $Re \approx 7500$ (Table 2) the a/b ratio is equal approximately to unity. Here we encounter multilayer movement of internal currents. With stipulated parameters of the water flow (Table 2), regardless of its state, the number of layers of internal currents will be about five. One of the parameters of the cross section of internal currents 2a can be computed using the formula

$$2a = \frac{0{,}31}{\sqrt[3]{Fr}}.$$

The 2a value is determined only by the Fr number and is not dependent on the Re number.

It is also not without interest to take a small excursion in the direction of some explanation of the fact of division of internal currents with use of their kinetic energy, which can be computed using the formula

$$E_{kin} = \frac{mV^2}{2},$$

where m is the mass of an internal current with a length of 1 cm ($\pi ab\rho$), ρ is water density.

If the constant parameters are not taken into account, then $E_{kin} \equiv abV^2$. The results of experiments (Table 4) show that the abV^2 value is retained despite the fact that there is a change in the size of the internal currents and the velocity of their movement. In other words, with a constant water discharge and different angles of trough slope the kinetic energy of the internal currents (bodies of revolution) is constant.

Thus, a decrease in the size of the bodies of revolution with an increase in the angle of trough slope (or the Froude number) can be attributed to the tendency of a water flow to expend a minimum energy on movement.

In general, it seems to the author that all cases of internal currents fit into Table 1 and the proposed classification of internal currents is confirmed. Each value of the Froude number corresponds to its family of water flows with definite parameters of internal currents characteristic only of them. Therefore, the internal currents corresponding to each box (Table 1) comprise a great range of such currents. The facts of their division with an increase in Reynolds numbers and explanation of the nature of their division on the basis of a minimum expenditure of energy on movement and a decrease in size with an increase in the Froude number are very interesting and important regularities of the internal structure of water flows. The results of this investigation, taking into account the studies made earlier by the author [1, 2], have theoretical and practical importance. They can be used in explaining many phenomena in nature and engineering and will accelerate the subsequent study of these interesting phenomena.

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AGROCLIMATIC EVALUATION OF POTENTIAL AND ACTUALLY POSSIBLE POTATO YIELD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 105-110

[Article by Doctor of Biological Sciences Kh. Tooming and P. Kh. Kyyva, Estonian Agrometeorological Laboratory and All-Union Scientific Research Institute of Agricultural Meteorology, submitted for publication 29 June 1978]

Abstract: The article describes a method for computing potential yield, taking into account the total receipt of photosynthetically active radiation and its probability on the basis of experimental data for the period 1975-1977 the authors analyze the factors determining the actually possible yield of potatoes under sprinkling conditions and with a natural precipitation regime. The actually possible yield and its probability in the Estonian SSR were computed for two varieties of potatoes.

[Abstract] Among the environmental factors for plants a special role is played by the sums of total radiation and photosynthetically active radiation (PAR). The APY sum is the energy reserve whose receipt determines the maximum possible level of photosynthesis and the potential yield (PY), that is, the yield possible under ideal weather conditions. Other factors -- soil and air temperature, precipitation, moisture reserves in the soil, etc. can be considered background parameters in the yield formation process. Background factors are rarely ideal. The degree of assimilation of solar radiation by plants in the production process and in the last analysis the actually possible yield (APY) are dependent on favorable background factors [10, 11].

The correlation between productivity and potato yield and background meteorological factors has been thoroughly investigated [1, 3, 7, 8, 13, 15, 16, 18]. Lesser attention has been devoted to study of the correlation between PY and APY of agricultural crops with the receipt of solar radiation in interrelationship with the water regime [2, 4, 10-12, 14]. Therefore, the objective of this article includes:

Table 1

Probability (%) of Total Radiation Sums $-\sum Q$ (Cal/cm^2), PY and APY (centners/hectare) of Raw* Biomass of Potato Tubers Under Sprinkling Conditions on Soddy-Calcareous Soils With Different Durations of the Period from Sprouting to Dying-Off of the Tops

Сорт 1	Даты всходов и конца роста 2	Показатели 3	4 Обеспеченность									
			10	20	30	40	50	60	70	80	90	100
Сулев 5	1 VI—20 IX	ΣQ	49,4	48,0	45,9	44,8	43,8	43,1	42,4	41,8	41,2	40,1
		ПУ 7	849	827	791	774	756	743	734	720	707	690
		ДВУ 8	595	580	550	540	525	515	510	505	490	480
	11 VI—20 IX	ΣQ	44,5	42,6	40,7	39,6	38,8	38,3	37,7	36,9	36,0	34,4
		ПУ	769	738	703	681	672	659	650	636	619	592
		ДВУ	530	515	490	480	465	455	450	440	430	405
	21 VI—20 IX	ΣQ	39,1	37,8	36,4	35,2	34,2	33,3	32,5	31,6	30,8	30,3
		ПУ	672	650	628	606	588	575	561	544	530	522
		ДВУ	465	455	430	415	405	390	385	380	370	355
Белорусский ранний 6	21 V—20 VIII	ΣQ	45,9	43,8	42,7	42,1	41,3	40,2	39,1	38,2	37,9	37,0
		ПУ	761	727	710	699	687	670	648	636	630	613
		ДВУ	550	530	515	500	490	480	465	455	450	440
	1 VI—20 VIII	ΣQ	40,8	39,0	37,6	36,6	35,7	34,8	34,2	33,6	33,1	32,7
		ПУ 7	676	648	625	608	591	579	568	557	545	540
		ДВУ 8	490	465	455	435	425	415	405	400	390	385
	11 VI—20 VIII	ΣQ	35,6	33,6	32,2	31,4	30,6	29,9	29,2	28,8	28,3	27,0
		ПУ	596	557	534	523	511	494	483	477	466	449
		ДВУ	425	400	380	375	360	355	350	345	330	320

KEY:
1. Variety
2. Dates of sprouting and end of growth
3. Indices
4. Probability
5. Sulev
6. Belorusskiy ranniy
7. PY
8. APY

*For finding the PY and APY of dry biomass the PY and APY values must be multiplied by 0.226 for the Sulev variety and by 0.176 for the Belorusskiy ranniy variety.

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-- evaluate the PY and its probability for two varieties of potatoes in the Estonian SSR;
-- quantitatively clarify the dependence of APY on the receipts of total radiation and evaporation sums;
-- quantitatively characterize the interrelationships between the sums of total radiation and precipitation in the Estonian SSR;
-- evaluate the APY of potato and its probability under both irrigation conditions and with a natural regime of precipitation on soddy-calcareous soils with a high agricultural background in the Estonian SSR.

The PY can be determined approximately using the formula

$$Y_{п} = 10\ \eta_{п} \frac{\Sigma Q}{q} k_{хоз}, \tag{1}$$

[η = pot; $X03$ = econ] where Y_{pot} is the PY (potential yield) in centners/hectare; η_{pot} is the efficiency of the crop or variety under ideal meteorological conditions (%) -- the so-called potential efficiency of the sowing, ΣQ is the total receipts of PAR (photosynthetically active radiation), in Cal/cm^2, k_{econ} is the coefficient of economic efficiency of the yield, q is the calorie content of the yield in Cal/g.

In order to determine the probability of PY it is necessary to know the probability of the sums of total radiation and PAR in dependence on the duration of the growing season for the variety. The probability of total radiation at the Tartu (Tyravere) actinometric station was determined using data from a 25-year observation series. The data for this station characterize well the mean radiation regime for the territory of the Estonian SSR. The beginning and end of the growing season can differ in individual years. Therefore, the radiation sums used by the Sulev variety in individual years in the Estonian SSR during the period from sprouting to the dying-out of the tops can vary in a great range from 30 to 50 Cal/cm^2; the corresponding limits for the Belorusskiy ranniy variety are from 27 to 46 Cal/cm^2. The mean sums of total radiation, encountered with about a 50% probability, in dependence on the duration of the growing season, vary for the Sulev variety from 34 to 44 Cal/cm^2, for Belorusskiy ranniy -- from 30 to 42 Cal/cm^2. In computing PY it must be remembered that the PAR sum is about 50% of the total radiation.

In order to determine the potential efficiency of a potato sowing, the authors, in collaboration with the Estonian Scientific Research Institute of Agriculture and Melioration, during the period 1975-1977 carried out special experiments with sprinkling [12]. A high agricultural background was created in experimental sectors. It was intended for obtaining a yield of tubers of about 500 centners/hectare. The quantity of applied fertilizers in this case was $N_{120}P_{185}K_{190}$ + 60 tons of manure. These experiments demonstrated that the potential efficiency of the Sulev variety in the PAR region is about 4% and for the Belorusskiy ranniy variety is about 3%.

The coefficient of economic effectiveness of the yield on the average is k_{econ} = 0.8 and the calorie content is q = 4.1 Cal/g [12]. With such initial data we carried out computations of PY and its probability. The determined PY values (Table 1) can also be used for determining the PY of other existing varieties if their potential efficiency, beginning and end of the growing season are known. For this purpose the data from Table 1 are multiplied by a factor which is determined as a ratio of the potential efficiency of the variety in percent to 4 in the case of mid-season maturing varieties and to 3 in the case of early varieties. With a probability of 50% the PY values are close to the mean long-term values. For the Sulev variety, in dependence on the duration of the growing season, they are 133-170 centners/hectare of dry biomass of tubers, which is about 585-750 centners/hectare of wet biomass with a mean content of dry matter 22.6%.

The mean long-term PY of the variety Belorusskiy ranniy is lower -- it varies in the range 90-120 centners/hectare of dry and about 510-690 centners/hectare of wet biomass of tubers with a mean content of dry matter 17.6%.

The extent to which a moisture deficit limits an APY close to the PY is revealed in an examination of the dependence of the APY on the evaporation sums (Fig. 1a), constructed on the basis of data from our experiments for 1975-1977. This correlation is close ($r = 0.94$, $p = 0.99$) and to a value $\sum E = 270$ mm is linear. It is virtually identical for the varieties Sulev and Belorusskiy ranniy both when sprinkled and without sprinkling. With higher $\sum E$ values the dependence becomes nonlinear. With $\sum E = 350$ mm (Fig. 1a) the APY is about 600 centners/hectare. The good correlation between the APY and the evaporation sums is attributable to the following circumstances:

1) The principal component of evaporation is its transpiration. Its [illegible]nsity is high when the stoma of the leaf is open. Open stomata in turn create good conditions for the diffusion of CO_2 into the leaf and for intensive photosynthesis.

2) The evaporation sums are determined by the action of a complex of factors, such as the sums of radiation, temperature and soil moisture, dew-point spread, etc., which are in potential correlation with the intensity of photosynthesis and with the growth of plants. The correlation between the potato yield and evaporation sums has a universal character: the same slope of the straight line was obtained for different varieties in Holland [17]. A correlation between the yield and the evaporation sums was also discovered for grain crops [19]. The correlation of yield with the moistening coefficient, which was close for perennial grasses [11], was less significant for potato.

The receipts of total radiation and PAR are used to the greatest degree under irrigation conditions. APY increases linearly with an increase in the sums of total radiation (Fig. 1b). With radiation sums of about 50 Cal/cm^2 APY is about 600 centners/hectare. The dependence of APY on the radiation sums is close ($r = 0.96$; $p = 0.99$). Accordingly, under conditions of an adequate water supply the limiting factor in the potato yield is the sums of total radiation and PAR. In the Estonian SSR such a situation is encountered in 20% of all years.

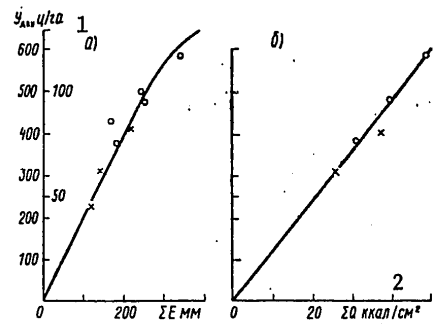

Fig. 1. Dependence of APY of potato of two varieties. a) on evaporation sums during the period from sprouting to dying-out of the tops; b) on the sums of total radiation during this same period. The dots are for the Sulev variety; the small crosses are for the Belorusskiy ranniy variety. along the y-axis: at left -- wet biomass, at right -- dry biomass in centners/hectare. The mean scaling factor for the dry biomass of the tubers is 0.20.

KEY:

1. APY/ centners/hectare
2. Cal/ cm^2

By using the dependence of APY on the total radiation sums (Fig. 1b) and the probability values for the total radiation sums (Table 1) we determined the probability of APY under sprinkling conditions (Table 1). It appears that the mean long-term APY (probability about 50%) of the Sulev variety falls in the range from 405 to 525 centners/hectare; for the variety Belorusskiy ranniy -- from 360 to 490 centners/hectare. The maximum radiation receipts also ensure maximum APY values.

In most cases the potential of high receipts of total radiation and PAR is not realized. In years with a great receipt of total radiation and PAR the precipitation sums are small (Fig. 2). The correlation of the mean republic precipitation sums and the total radiation sums for the June-September period is negative ($r = 0.65$; $p = 0.99$). For the Tartu region we also constructed the dependence of the evaporation sums on the basis of the data in [5] on the total radiation sums. It differs little from the correlation of the mean republic precipitation sums and the radiation sums (Fig. 2, circles). This is natural, since the initial and final moisture reserves in the soil are approximately equal and the precipitation sums for the period June-September are virtually equal to the evaporation sums during this period. Radiation and water are energetically in equilibrium if the evaporation sum during the growing season, in combination with the total radiation sum, falls within the limits of direct evaporability (Fig. 2a). In such a case the radiation sum and the quantity of evaporated water are harmoniously combined in the yield formation. Such a situation is not always realized in Estonia. Water is adequate and even in excess in 42% of all the considered years. In 58% of the considered years the moisture deficit is up to 200 mm. As an exception, in all cases when the sum of total radiation during the June-September period is greater than 44 Cal/cm^2, the APY is limited by an inadequacy of water (Fig. 2). Using the dependence of the evaporation sums on radiation sums and the dependence of APY on the evaporation sums (Fig. 1a) it is possible to find the APY of potatoes in individual years, the APY probability (Fig. 3) and the yields which are not received due to a moisture deficit. It appears that in the years 1955, 1959, 1963, 1969, 1975, when the total radiation sums for the June-September period exceeded 48 Cal/cm^2, the undercollection of yield due to a moisture deficit was from 175 to 340 centners/hectare. On the average, the undercollection of yield or the possible yield increment as a result of irrigation is about 120 centners/hectare. The moisture deficit and yield undercollection values are approximately of the same order of magnitude according to data from Strunnikov [9] for the Northwestern USSR.

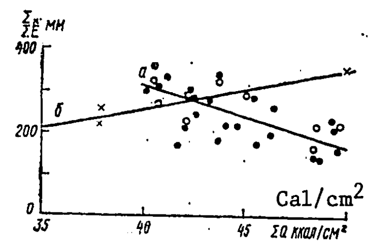

Fig. 2. Correlation of the mean precipitation sums for the Estonian SSR and the total radiation sums (dots) for the period June-September (inclusive), correlation of evaporation sums and total radiation sums (circles) for this same period in the Tartu region (a) and the dependence of evaporation sums for a potato crop on the total radiation sums (b) under conditions of adequate water supply (experimental data).

In the case of irrigation the APY increases proportionally to the radiation receipts. In the case of a natural precipitation regime the situation is more complex -- low APY values (Fig. 3) are encountered in years with a high receipt of total radiation and a small quantity of precipitation. However, high APY values are noted in years with an adequate water supply, but small radiation receipts. The difference in the maximum APY values with irrigation and with a natural precipitation regime (Fig. 3) is caused by an inadequacy of radiation in years adequately supplied with precipitation.

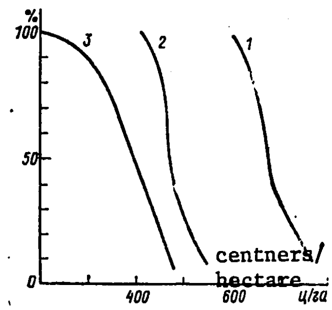

Fig. 3. Probability (%) of different potato yields (centners/hectare) of the Sulev variety; period from sprouting to dying-out of the tops -- 11 June-20 September. 1) PY, 2) APY with irrigation, 3) APY with natural precipitation regime.

It is important to note that as a result of irrigation here, to the highest degree there is an increase in the level of a yield ensured by 100% -- from 210 to 405 centners/hectare (Fig. 3). In order to increase a yield level whose probability is less than 50% the role of irrigation is small. It can therefore be concluded that the basic advantage of irrigation is not an increase in the maximum level of APY with a low probability, but a considerable increase in the minimum 100% ensured APY level. For this purpose conditions are created by irrigation which ensure the maximum receipts of PAR in sunny years with few clouds.

There is a great gap between the APY and PY curves (Fig. 3). This indicates that the potato yield is also limited by other background factors which we have not examined, especially the soil and air temperature. A considerable reserve in increasing APY is expressed in a total liquidation of the under-collection of yield caused by phytophthora.

In the programming of yield it is necessary to be oriented on an APY level corresponding to a sowing efficiency of 3-4% and a probability 50%. Under irrigation conditions with a 50% probability it is possible to program a yield of the Sulev variety of about 460-480 centners/hectare and for the Belorusskiy ranniy variety -- about 420 centners/hectare. In a natural precipitation regime the 50% probability of a yield for the Sulev variety is about 390 centners/hectare.

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SPECTRAL MEASUREMENTS OF ABSORPTION OF SOLAR RADIATION BY INDUSTRIAL HAZE

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 111-113

[Article by Candidates of Physical and Mathematical Sciences A. I. Ivanov and I. A. Fedulin, V. N. Korovchenko, Astrophysical Institute Kazakh Academy of Sciences, submitted for publication 5 June 1978]

Abstract: Using surface spectral measurements of direct and scattered solar radiation in eight parts of the spectral region 0.405-1.01 μm it was possible to find its absorption by industrial haze. The corresponding measurements were made under conditions of a highly turbid atmosphere in a large city at negative air temperatures. Comparison of the measured absorption values and their spectral dependence with available data in the literature on laboratory experiments gives basis for assuming that the detected absorption was caused, for the most part, by soot and particles of uncombusted coal.

[Text] In order to evaluate the influence of industrial haze on the environment it is important to know its capacity for absorbing solar radiation in different parts of the spectrum. The corresponding investigation is carried out most correctly when the industrial aerosol is in its natural state, that is, the particles are suspended in the air. This is entirely explicable because with any method for the sampling of aerosol to a greater or lesser degree its transformation occurs and accordingly the results may differ from the true results.

Below we describe the method and cite the corresponding results of investigations of spectral aerosol absorption at Alma-Ata in the visual and near-IR spectral regions. The corresponding measurements were made in late October and November at negative air temperatures. Under such conditions there is a layer which is uplifted by several hundreds of meters from the earth's surface, a temperature inversion which impedes free exchange with the air masses situated above. In addition, the singular local relief leads to virtually complete windlessness. These conditions, plus such a powerful aerosol generator as a major city with a well-developed industry and transport system, cause an increased concentration of industrial aerosol.

Two instruments were used in carrying out measurements: a visual electrophotometer, supplied with interference light filters, and an IR spectroelectrophotometer, constructed on the basis of an IKS-11 monochromator. The half-width of transmission of the interference light filters did not exceed 0.008μm and the spectral width of the monochromator slit was 0.01μm. The investigations were made at eight wavelengths in the spectral range 0.405-1.01μm, situated in the atmospheric windows of transparency. Direct and scattered (solar almucantar) solar radiation was measured. Further computations were made in the following way. In principle, by carrying out measurements of direct solar radiation, that is, by determining the illumination of a standard screen, oriented perpendicularly to the direct solar rays, with different solar zenith angles $Z_\odot$ it is possible, by the classic Bouguer method, to determine the optical thickness of extinction τ_B:

$$E_m = E_0 \exp(-\tau_б m_\odot). \tag{1}$$

[$б$ = B] Here E_m, E_0 is the illumination of the screen by direct solar rays at the earth's surface and beyond the limits of the atmosphere respectively; $m_\odot$ is atmospheric mass in the direction of the sun.

However, an invariable condition for the use of expression (1) is optical stability of the atmosphere over the entire course of the measurements. Here by the term optical stability we have in mind a constancy of the optical thickness of extinction. Under conditions of urban measurements it is known that this condition is not satisfied. Therefore, the τ_B value was found by the method of exoatmospheric sun brilliance. In order to apply this method the instruments were supplied with sources of constant brightness. Therefore, in place of (1) we write the expression

$$\frac{I_m}{I_л} = \frac{I_0}{I_л} \exp(-\tau_б m_\odot), \tag{2}$$

[$б$ = B; $л$ = ss] where I_m, I_0, I_{ss} are the instrument readings proportional to the brightness of a standard screen at the earth's surface, beyond the limits of the atmosphere and the brightness of a standard source respectively.

The use of the ratios I_m/I_{ss}, I_0/I_{ss} makes it possible to exclude the possibility of any change in response of the apparatus to measured radiation, and this means the ratio I_0/I_{ss} is a constant for the particular instrument. For each of the employed instruments this constant was first determined by extrapolation of the Bouguer straight lines to $m_\odot = 0$ using data from measurements in a rural place for selected optically stable days. In determining I_0/I_{ss} we also took into account a seasonal correction for the change in the distance between the earth and the sun. As a result, expression (2) makes it possible to determine the optical thickness of extinction for each moment in time as

$$\tau_б = \frac{\lg\left(\frac{I_0}{I_л}\right) - \lg\left(\frac{I_m}{I_л}\right)}{0.434\, m_\odot}.$$

The value of the optical thickness of extinction can be written in the form of the sum

$$\tau_{\text{б}} = \tau_{\text{р}} + \tau_{\text{п}} = \tau_{\text{р}}^{\text{а}} + \tau_{\text{п}}^{\text{а}} + \tau_{\text{р}}^{\text{м}} + \tau_{\text{п}}^{\text{м}}, \tag{3}$$

[б = B; p = sc(attered); п = ab(sorbed)]

where the subscripts "a" and "m" denote the aerosol and molecular components of the atmosphere and "sc" and "ab" denote scattering and absorption.

The component τ_{sc}^{m} is easily computed using the well-known Rayleigh-Cabannes formulas. The term τ_{ab}^{m} in our case is different from zero only in certain parts of the spectrum where there is absorption by ozone in weak Chappuis bands. Since we know the mean ozone content for a particular place and season [3], then τ_{ab}^{m} was also easily computed.

It is most complex to find the component τ_{sc}^{a}. We will discuss its determination in greater detail. Using brightness measurements in the solar almucantar it is possible to find the so-called brightness indicatrix using formally the brightness formula from the single scattering theory

$$\mu_H(\varphi) = \frac{B(\varphi)}{E_0 \exp(-\tau_{\text{б}} m_{\odot})\ m_{\odot}},$$

where $B(\varphi)$ is sky brightness at the angular distance φ from the sun.

Due to the effects of multiple scattering and reflection of light from the underlying surface the value $\mu_H(\varphi)$ will be somewhat greater than the scattering indicatrix $f(\varphi)$. In accordance with the known formula, the optical thickness of scattering can be determined in the following way:

$$\tau_{sc} = 2\pi \int_0^{\pi} f(\varphi) \sin\varphi \, d\varphi.$$

Substituting the brightness indicatrix $\mu_H(\varphi)$ into the integrand in place of $f(\varphi)$, we obtain

$$\tau_H = 2\pi \int_0^{\pi} \mu_H(\varphi) \sin\varphi \, d\varphi.$$

It is customary to call the total optical thickness of scattering τ_H. It is a convenient characteristic of the total scattered flux. The authors of [2] examined the possibility of determining the optical thickness of scattering from τ_H, determined from measurements. It was assumed that τ_H is dependent, for the most part, on τ_{sc} and local albedo q. However, the indicatrix effects are weak and can be taken into account empirically. Then, finding from measurements of τ_H and q (it is sufficient to estimate the latter value from data in the literature) and using known computations [5], it is possible to determine τ_{sc}. The method was checked on the basis of extensive data for the near-IR spectral region and yielded good results. Later the method was modified, which made possible its successful use both in the IR and in the visible regions of the spectrum in the absence of appreciable absorption [3].

The use of this method in our case required additional investigations due to a possible appreciable absorption of radiation by industrial haze. In actuality, in the presence of appreciable absorption by a medium with any definite optical thickness of scattering τ_{sc} will correspond to a lesser τ_H value than in the case of a nonabsorbing medium with the same τ_{sc}. Naturally, it is understood that in both cases the albedo of the underlying will be one and the same. Such an effect is associated with the absorption of radiation multiply scattered and reflected from the underlying surface.

In order to evaluate the possibilities of the method applicable to an absorbing medium we will use the results of our measurements in the water vapor absorption band $\rho\sigma\tau$ (λ_{max} = 0.94μm) and the near-lying spectral sectors free of molecular absorption (measurements in a rural area). By means of interpolation we will determine the values $\tau_H(\lambda = 0.94\mu m)$ which would be observed if water vapor was absent in the atmosphere. However, real τ_H ($\lambda = 0.94\mu m$) are known from experimentation. The difference in the $\tau_H(\lambda = 0.94\mu m)$ values found in this way will be the greater the more water vapor there is in the atmosphere, and as was already mentioned above, is related to the absorption of radiation multiply scattered and reflected by water vapor. Thus, drawing an analogy, it is possible to make a quantitative estimate of the considered effect, also associated with aerosol absorption. The analogue of aerosol absorption here will be absorption by water vapor, whose content is known to us. To be sure, when making such an analysis we took into account the identity of other measurement conditions, including the spectral resolution of the apparatus [4]. As a result it was found that for the mean optical thicknesses of scattering and stipulated aerosol absorption $\tau^a_{ab}(\tau^a_{sc} + \tau^a_{ab}) = 0.5$ the use of the method described above for determining the τ_{sc} values leads to an error in the result of approximately 2%.

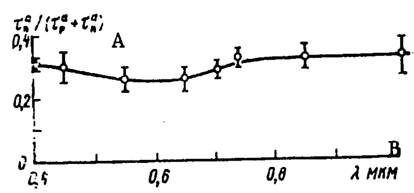

Fig. 1. Spectral dependence of fraction of aerosol absorption on total aerosol extinction.

KEY:

A. $\tau^a_{ab}(\tau^a_{sc} + \tau^a_{ab})$
B. μm

Thus, in accordance with [3], we determined the optical thickness of scattering and the optical thickness of aerosol scattering τ_{sc}, $\tau^a_{sc} = \tau_{sc} - \tau^m_{sc}$. Now, using expression (3), it is easy to find the optical thickness of aerosol absorption τ^a_{ab}. The averaged spectral dependence of the fraction of aerosol absorption on total aerosol extinction $\tau^a_{ab}/(\tau^a_{sc} + \tau^a_{ab})$ is shown in Fig. 1. The corresponding data were obtained using 70 series of measurements.

It should be mentioned that the described method without carrying out simultaneous measurements in any purity "standards" (rural area near a city) makes it possible, in principle, to obtain only the integral characteristics of the aerosol, suspended in the entire thickness of the atmosphere, being of independent interest. However, in our case it can be asserted that the detected absorption is caused specifically by industrial haze, since an analysis of the results of long-term measurements in the adjacent rural area gives a level of absorption by natural aerosol not exceeding 10% [3]. Since in the ratio considered above the τ^a_{ab} value was governed, for the most part, by the industrial haze under an inversion, whereas τ^a_{sc} relates to the entire thickness of the atmosphere, an absorption value of approximately 30% can be regarded as the lower boundary for industrial haze itself.

An interesting characteristic of the detected absorption is its neutral dependence on wavelength. This fact, and also the absorption values themselves and the results of laboratory investigations [1] makes it possible to assume that for the most part absorption is caused by soot and particles of uncombusted coal.

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UDC 502.7(100)

INTERNATIONAL SYMPOSIUM ON COMPREHENSIVE GLOBAL MONITORING OF ENVIRONMENTAL CONTAMINATION

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 114-118

[Article by Doctor of Technical Sciences F. Ya. Rovinskiy, Institute of Applied Geophysics, submitted for publication 24 January 1979]

Abstract: This paper gives a review of reports at the International Symposium on Comprehensive Global Monitoring of Environmental Contamination (Riga, 12-15 December 1978).

[Text] In the course of recent decades there has been accumulation of a great many facts concerning the unfavorable effect of human society on the surrounding environment, in large part associated with its contamination. Fears have arisen that the accumulation of harmful substances in the biosphere is leading not only to local changes in the environment, but can also assume a global character, threatening the very existence of life on earth.

Thus, the need has arisen for organizing a special system for observing the state of the biosphere. The plan of action adopted by the UN Environmental Conference (1972, Stockholm) provided for the creation of a global system for monitoring the environment..An important step toward creating a global system for monitoring the environment was the intergovernmental conference called by UNEP in 1974 in Nairobi, Kenya, where recommendations were formulated on determining the principles and goals of the global system for monitoring the environment, on priority criteria and a list of indices of state of the environment to be monitored and on a number of other fundamental directions in planning and developing the global system for monitoring the environment.

The scientific organization of the global system for monitoring the environment is being carried out within the framework of Project No 14 in the UNESCO program "Man and the Biosphere." The WMO is the international organization which is working on the practical implementation of the global system for monitoring the environment.

Over the course of recent years much work has been carried out in the member countries of the Socialist Economic Bloc. A coordination center for the problem of a global system for monitoring the environment has been established and the cooperation program involves more than 80 institutes in seven countries in the European region.

The results of scientific research in this field were discussed at an international symposium on comprehensive global monitoring of contamination of the environment which was held in December 1978 in the USSR (Riga). This symposium was organized by the WMO and under the UNEP program, in collaboration with the USSR State Committee on Hydrometeorology and Environmental Monitoring and the Academy of Sciences Latvian SSR. Participating were scientists and specialists of Bulgaria, Great Britain, Hungary, East Germany, Canada, Poland, USSR, West Germany, Czechoslovakia, Switzerland, and also representatives of the WMO, UNEP and UNESCO.

The following sections operated together with the plenary sessions, where the conferees examined the scientific basis and purposes of comprehensive global monitoring:

"Comprehensive Global Monitoring of Levels of Contamination of the Environment. Principles for the Organization of Monitoring Systems";

"Study of the Propagation and Cycling of Contaminating Substances in Natural Media";

"Evaluation and Prediction of the Influence of Contaminating Substances on the Ecosystem and Climate."

More than 60 reports were presented at the symposium.

The chairman of the organizing committee of the symposium, Corresponding Member USSR Academy of Sciences Yu. A. Izrael', presented the scheduled report "Scientific Validation and Fundamental Principles of Monitoring of the Environment and Climate." In his report he formulated the basic definitions and established the monitoring components. By "monitoring" is meant such a system of observations which makes it possible to discriminate changes in the state of the environment occurring under the influence of anthropogenic activity. This system includes observations of changes in the state of the environment and the sources of these effects; evaluation of state of the environment; prediction of the state of the environment. Thus, monitoring differs from earlier existing observation systems, although provision is made for use of the necessary information, for example, meteorological, hydrological and other data.

The basis for comprehensive monitoring is an integrated approach, providing not only for observations of contamination of all media (multimedium monitoring), but also detection of reactions to this effect in biological, ecological and other systems. Therefore, observations of changes in the state of the environment and sources of modification include the following: geophysical, geochemical, physiographic data, and also data on the composition and character of contaminations of all media; observations of sources of contaminations and other modifying factors, observations of biotic reactions to different agents and changes in the environment; observations of the reactions of major systems (weather, climate, ozone layer).

An evaluation of changes in the state of the environment will answer the question of the degree to which the environment deviates from its admissible state, will clarify the reason for such deviations and will establish the losses caused by such a deviation. It is important in this process to formulate criteria of an acceptable state of the environment and also the critical and admissible modification of the environment. For the purposes of a scientific validation of monitoring it is necessary to carry out comprehensive investigations and analysis of the modification of different anthropogenic factors at the level of populations and ecosystems, ascertain the critical factors in the modification, such as critical chemical forms of contaminating substances, and determine the most sensitive elements of the biosphere. Here an important consideration in monitoring is determining the priority in observations so that it will be possible to obtain a sufficiently complete picture of the state of the environment at the present and in the future. In organizing monitoring provision must be made for comprehensive observations at levels with different intensity of modification -- the regional and global impact; special attention must be given to background observations, and here the most important role is played by monitoring in biospheric reserves.

The author has an interesting approach to determination of the place of monitoring in the overall system of measures for preserving the environment, its interaction with control in the field of preservation of the environment. It is more economical and desirable to exert an influence on the sources of contamination or other factors of anthropogenic origin than to contend with a modified (such as contaminated) environment.

A communication by F. Sell and K. Wallen (UNEP) examined the fundamental tasks, principles and content of work on creating a global system for monitoring the environment. At the present time, within the framework of the global system for monitoring the environment, a number of projects are being formulated which are directed to a clarification of the influence of anthropoenic activity, primarily contamination of the environment, on climate, human health, state of the ocean, different resources, etc.

A. Keller (WMO), in his report, gave a review of activity of the network of regional and base stations for monitoring atmospheric contamination and precipitation; he examined the program for this monitoring and the criteria used in placement of stations. At present about 150 regional and base stations are operating or are planned. These are situated on all the continents in different climatic and physiographic zones. For the purposes of methodological direction of these observations the WMO is issuing the necessary recommendations, is cooperating in carrying out intercalibration of methods and instruments, etc.

A number of reports dealt with the fundamental principles of comprehensive global monitoring and criteria for placing the network of stations for comprehensive monitoring.

R. E. Munn (Canada) emphasizes that the idea of comprehensive monitoring, when measurements are made at one time in one place and take in the atmosphere, soil, snow cover, surface and ground water, biote, including its reaction to modification, is extremely attractive. He noted that for the first time such comprehensive observations have been initiated in the USSR. The reports of A. J. Fairclaf and G. N. Port (Great Britain) pointed out that the principal tasks of monitoring are supplying information to governments and the public on the state of the environment and also ensuring the planning of measures for its preservation and evaluating their effectiveness, as well as specific monitoring of environmental contamination. The reports emphasize the need for practical implementation of global monitoring of the environment.

A report by B. Uzunov and I. Iliev (Bulgaria) was devoted to the principles of interaction between the global monitoring system and the national and regional observation systems and information on environmental contamination. The global system for monitoring the environment, in contrast to the national monitoring systems, which are examined in the examples of the USSR, France, West Germany, Italy and Bulgaria, will reflect the base state of the biosphere.

The reports of L. Shepezi (Hungary), M. Ye. Berlyand, Ye. S. Selezneva, O. P. Petrenchuk, B. I. Styro, K. K. Shopauskas (USSR) and R. Khrynevic (Poland) examined data from the operation of stations for monitoring atmospheric contamination and precipitation under the WMO program. An analysis indicated that global contamination of the atmosphere exceeds the anticipated level predicted on the basis of traditional observations. The near-surface concentrations differ in dependence on the scale of observations -- global, continental, regional, local. The many observational stations of the Socialist Economic Bloc countries and cooperation in the field of international comparison of methods and instruments, which was carried out in 1973 and 1978 in the USSR, are of considerable importance in the general network.

The principle of paired stations, one of which is situated in the city, broadens the possibility of interpretation of observational data. Actinometric and other data from background stations in the USSR indicate a cleaner atmosphere in comparison with some other countries. A tendency to an increase in air dust content outside cities is not entirely clearly manifested in the long-range picture. Systematic investigations of the chemical composition of precipitation made it possible to refine the concepts of background and regional levels of atmospheric contamination, which must be taken into account in the placement of background stations. In the USSR there are 70 stations in operation for study of the chemical composition of precipitation. Long-term observations indicate that over a period of 15-20 years the mineralization of precipitation in the western regions of the European USSR increased, primarily, due to sulfates, although the pH of sulfur is 5-6. Data on the composition of cloud water are representative as a background. Some ideas were developed on the mechanism of washing-out of impurities by precipitation.

The possibility of an influence of anthropogenic activity on climate and the ozone layer was outlined in the reports of Corresponding Member USSR Academy of Sciences M. I. Budyko and V. L. Tal'roze, et al. (USSR). The increase in the CO_2 concentration during the last century was 12-13%, and in the 22d century the mass of atmospheric CO_2 can increase by a factor of 6-8 in comparison with the 19th century. According to different models, this will lead to an increase in the mean temperature at the earth's surface by 1-1.5°C already by 2000, which will result in a considerable redistribution of moisture and heat; later there can be a radical restructuring of environmental conditions. The prevention of a breakdown of ozone in the stratosphere under the catalytic influence of a number of substances of anthropogenic origin first of all requires the organization of monitoring of both ozone itself and these substances. The required accuracy of these measurements must not be inferior to the present-day accuracy of laboratory measurements.

A number of reports were devoted to the practical results of comprehensive monitoring at the background level. A report by F. Ya. Rovinskiy, et al. (USSR) dealt with cooperation of the interested member-countries of the Socialist Economic Bloc on the creation of subsystems in the global system for monitoring the environment. A total of 22-25 stations will be created for background comprehensive monitoring and these will carry out coordinated observations under a unified program using standardized methods; seven such stations are situated in the territory of the USSR in biospheric reserves, and in addition, already beginning in 1976, systematic observations have been made at Borovoye (Northern Kazakhstan). The report gave an analysis of observational data on the content of dust, sulfur gas, 3,4-benzopyrene in the atmosphere, mercury, lead, cadmium, and arsenic in all media. Actinometric observations characterize the atmosphere in this region as "pure" according to the WMO classification.

A report by W. R. Schell (United States) discussed research data on the behavior and distribution of toxic substances among media at three levels: global, as a result of global fallout, regional, where toxic metals enter the marine ecosystem of the gulf, and local, where radionuclides from a nuclear explosion were formed (Bikini atoll). The paper gives an interesting relationship between the necessary and toxic levels of the content of a number of metals in domestic animals, which varies from 40 (zinc) to 200 (manganese), D. D. Kelly (United States) and E. T. Degens (West Germany) examined the background levels, biogeochemical cycle of CO_2 and its content in the past. It was established on the basis of observations in Alaska that there can be rather high fluctuations and seasonal changes in the atmospheric content of CO_2 and the CO_2 content in lake waters; an important role in exchange between the atmosphere and ocean is played by arctic ice. Temporal and meridional variations of small atmospheric impurities were examined in a report by K. Hanson (United States). Particular attention is devoted to CO_2 and freons, which constitute a danger for the ozone layer. A report by N. V. Moore (Great Britain) pointed out that monitoring of residues of pesticides in the tissues of birds, in combination with monitoring of their numbers and range, have made it possible to evaluate the effectiveness of the 1961 ban on the use of persistent chlororganic pesticides.

The reports of Corresponding Member USSR Academy of Sciences Yu. A. Izrael', et al., and V. A. Ionov, et al. (USSR) discussed the problems involved in the monitoring of the atmospheric transport of contaminating substances over great distances. The program of such observations is a part of the global system for monitoring the environment. It should supply information on the transport of contaminating substances across the boundaries of countries. The monitoring system will include surface stations, regular aircraft and shipboard observations. Remote and aircraft methods for monitoring sulfur gas, mercury, ammonia and pesticides were examined.

The reports of A. I. Simonov (USSR), A. Preston, A. D. MacIntyre (Great Britain) and E. Levy (Canada) examined the problem of marine monitoring, priority requirements, regional and global aspects, comprehensive approach in which observations include water, air and precipitation, bottom deposits and lake and sea organisms. Long-term observations must first of all be carried out in remote regions of the world ocean in order to reflect the overall changes in the marine medium. One of these regions is Charlie station in the North Atlantic Current, where monitoring is carried out on Soviet weather ships. An important role is played by the determination of the balances of contaminating substances and forecasts and recommendations based on this for reducing sea contamination. Hydrocarbons, the most significant form of contamination in the seas and oceans, is devoted great attention. It has been demonstrated that hydrocarbons of anthropogenic origin are present everywhere, in the atmosphere over the ocean, in the surface film, in the bottom deposits, water and organisms.

The reports of V. T. Kaplin, A. A. Ivanova and A. A. Matveyev, L. K. Sebakh (USSR) were devoted to problems relating to the background monitoring of surface waters. An evaluation of the state of natural waters (rivers, lakes, etc.) is made on the basis of special hydrochemical observations, whose program includes bottom deposits, and also provides for the necessary hydrological observations. Monitoring in Lake Baykal is one of the examples of a comprehensive approach to background observations in which there is a possibility for systematically ascertaining the balance of chemical substances in a lake, taking into account entry from the atmosphere and from inflowing rivers.

A large group of reports was devoted to ecological and biological monitoring. In a report by L. M. Filippova, et al. (USSR) there was a discussion of still poorly developed problems involved in the monitoring of responses of the biote to anthropogenic effects at the background level, which is intended for biospheric reserves. The basis for the evaluation and prediction of the state of ecosystems can be the dose-effect dependence for tested species, investigated under the controllable conditions of ecostats in combination with field observations and mathematical modeling for ecosystems grouped by classes. The relationship between field observations and investigations of test objects should be optimized, using as a point of departure the required reliability in predicting the state of ecosystems and expenditures on monitoring.

A report by V. Ye. Sokolov and N. N. Smirnov (USSR) set forth a broad approach to the monitoring of the biological component of the biosphere, requirements on the registry of species composition, structural and functional characteristics of biological systems. The reports of K. Niomarkai and D. Shash (Hungary) and J. F. Farrar and J. R. Thompson (Great Britain) examined the effects of the influence of air contamination (by dust, sulfur gas, ozone, etc.) on surface vegetation. It is shown that the changes in tree leaves and grassy plants observed under urban conditions or near industrial objects are caused by atmospheric contamination, but these effects cannot be detected at the background level. The reports of Ye. Ye. Syroyechkovskiy and A. V. Denisova and L. D. Voronova and A. V. Denisova (USSR) give materials on the accumulation of chlororganic pesticides in wild animals which take in these substances as a result of circulation in the biosphere. A study was made of land and water birds, rodents, predator mammals, that is, animals at different trophic levels. A number of species can serve as an indicator of pesticides in the environment.

The reports of A. V. Tsyban' (USSR) and R. W. Reisbrath and B. W. de Lappe (United States) related to the biological monitoring of marine ecosystems. The first of these gave a basis for the monitoring of ecosystems in the Baltic Sea; particular attention is given to the microbiological component, playing an important role in the destruction of some contaminating substances. The author correctly mentions the still inadequate study of the joint effect of different substances on lake and sea organisms.

The second report is devoted to a study of the patterns of accumulation of different substances by mollusks, including chlororganic compounds (for example, PCB), in the California region. Extensive data have been obtained on the coefficients of accumulation in dependence on different ambient conditions and it is demonstrated that the mollusks can serve as indicators of contamination of the sea medium. The reports of O. M. Kozhova, G. P. Andrushaytis and N. M. Trunov, et al. (USSR) examined the influence of contamination on lake and river organisms in fresh-water systems. In the first report it was demonstrated that the use of ecological mapping is of great importance in such a unique water body as Baykal; this includes an evaluation of the composition, distribution and functional state of associations of all trophic levels with the use of mathematical ... .ing. This approach made it possible to detect some anthropogenic changes and can be proposed for a system for the monitoring of Baykal. Interesting energy approaches to anthropogenic changes in ecosystems in fresh water bodies are developed in the second report. The third report discusses the feasibility of the use of nonspecific cellular and subcellular reactions for monitoring purposes.

The reports of V. A. Kovda and A. S. Kerzhentsev, L. M. Shabad, Yu. P. Badenkov and B. K. Blinov, et al. (USSR) discussed the problems involved in the migration and circulation of anthropogenic substances in the environment. The substances are transported by moving media and are incorporated in the geochemical, trophic and other migration paths. The path followed, the accumulation or scattering of substances, are dependent both on the environmental conditions and on the properties of these substances. The accumulation of toxic, especially carcinogenic substances of the 3,4-benzopyrene type, in the higher links of trophic systems can have particularly unfavorable consequences. Its constant ejection into the atmosphere creates a definite background around man, and therefore the monitoring of 3,4-benzopyrene is extremely timely. Interesting data on the migration of a number of heavy metals in the "atmosphere-river runoff-sea lagoon" system were obtained in the Sikhote-Alin region; they can be very useful in organizing background monitoring in this biospheric reserve. Model field experiments with some heavy metals made it possible to establish the surface runoff coefficients (mercury 8.7%, lead 1.3% in the first year); a major contribution to the contamination of plants by DDT and other chlororganic compounds is made by aerial migration.

A number of reports examined the modeling of different aspects of the behavior of substances in the environment or the state of natural systems. The model of circulation of contaminating substances among geophysical media, developed in the report of V. M. Koropalov and A. Kh. Ostromogil'skiy (USSR), made it possible to give an evaluation of macroscale contamination effects. A model of the "chamber" type is employed, realized in the form of a system of linear differential equations; constant coefficients have been adopted for a global scale. The problems of evaluating the global balances of toxic substances are analyzed in a report by L. J. Milask (United States). The mathematical model of an exogenous succession, the characteristic state of present-day ecosystems under the influence of anthropogenic factors, is described in a report by S. M. Semenov (USSR). This model is one of the prognostic elements in the ecological monitoring system. From this model, in particular, follow the recommendations for biological monitoring, for example, the coefficient of reproduction of the observed species. The reports of L. M. Galkin (USSR), M. Zier, R. Schenk (East Germany) were devoted to the peculiarities of models of diffusion of impurities in inhomogeneous media (water and air media).

A description of the methods for background monitoring of contaminating substances and accompanying factors was given in the reports of F. Ya. Rovinskiy, et al., N. S. Vol'berg and Z. G. Tul'chinskaya, E. I. Babkina, et al. (USSR), K. Gravat (United States), B. P. Strekozov, et al., N. A. Petrov and A. V. Karaushev and B. G. Skakal'skiy (USSR).

In general, the reports and discussions at the symposium demonstrated that scientists of different countries are actively working on the problem of observation, evaluation and prediction of the state of the environment; a resolution adopted at the symposium was directed to the further development of research in this timely field.

REVIEW OF MONOGRAPH BY A. M. SHUL'GIN: AGROMETEOROLOGIYA I AGROKLIMATOLOGIYA (AGROMETEOROLOGY AND AGROCLIMATOLOGY), Leningrad, Gidrometeoizdat, 1978

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[Article by Candidate of Geographical Sciences V. A. Sennikov]

[Text] The author of this newly published text, Professor A. M. Shul'gin, for many years taught a course in agrometeorology and agroclimatology in the Geography Faculty of Moscow State University. The reviewed study aid is a result of many years of work, research and direct experience of this professional educator. Although the text is intended for students at colleges studying in the "Meteorology" field of specialization, its content makes it possible to count on a broader range of readers. Thus, the monograph will unquestionably be of interest to a great army of students at agricultural colleges and natural geography faculties at teachers' institutes, specialists at agricultural experimental institutes and scientific research institutes, and also practical workers in agriculture. Therefore, the publication of this study aid by Professor A. M. Shul'gin is very timely.

The book is compact and small in volume (12.5 printer's sheets, 200 pages), but extensively covers the problems treated. This can be judged from a brief review of the monograph's contents.

The first two chapters define the subject of agrometeorology and agroclimatology and discuss their importance for agriculture and also research methods. The author has succeeded in saturating this seemingly traditional introductory part with considerable factual material. Here he clearly defines the problems in the studied disciplines, their place and relationship to related sciences. It is only a pity that the list of problems does not include such a problem as the development of new and improvement of existing methods of agrometeorological observations.

The brief history of the science defines the principal stages in its development and mentions the names of leading scientists. The author mentions the organization not only of the USSR Agrometeorological Service, but also the status of agrometeorology abroad.

The methodological principles of agrometeorology as a science were examined by the author from the clear points of view of Marxist-Leninist philosophy. For example, it was shown how the fundamental dialectic laws (denial of denial, transition of quantity into quality, etc.) can be applied to agrometeorological objects. There is emphasis on the interrelationship and intercausality of natural factors in the process of cultivation of agricultural plants. A number of plant cultivation and agricultural laws on which agrometeorological research is based are given.

In a special section of the second chapter the author explains the concept of agrometeorological and agroclimatic indices.

The subsequent arrangement of the textual material is unusual. Taking as his basis the natural periodization of natural phenomena to which agricultural production conforms, the author examines agrometeorological conditions separately in the warm (third chapter) and cold (fourth chapter) periods of the year.

The exposition of agrometeorological conditions in the warm period of the year begins with a section on the principal biological laws of growth and development of plants and the formation of their yield. Here the author expresses and validates the fundamental position that phenological phenomena do not adequately cover the processes of formation of different plant organs and especially those which form the yield of agricultural crops. Accordingly, the text gives attention to the need for taking the stages in organogenesis into account. This is already being done in the carrying out of many agrometeorological investigations and also in the routine servicing of agriculture.

Among the total diversity of agrometeorological factors determining the productivity of agricultural plants, the author examines the most important: solar radiation, air and soil temperature, moisture. Their role is demonstrated using the most recent attainments in agrometeorology. Unfortunately, the text does not give a definition of photosynthetically active radiation.

In the third chapter we should particularly note three sections which are important in both theoretical and practical respects. These are the exposition of multifactor relationships between plant yield and agrometeorological conditions, modeling of processes in agrometeorology and principles for the programming of the yields of agricultural crops.

In describing the agrometeorological conditions for the cold season of the year the emphasis has been put on the snow cover, temperature regime of the air and upper soil layers, and also the complex of agrometeorological conditions ensuring the wintering of agricultural plants and the resistance of plants to winter cold.

A special chapter, the fifth, is devoted to weather phenomena unfavorable for agriculture. The author examines their origin, essential characteristics, geographical distribution and measures for contending with drought, dust storms, frosts (winterkill, rotting from wetting, withering, ice crust, heaving, dessication). In our opinion, the material in this chapter would be received better if each of the unfavorable phenomena was described separately, beginning from its origin and ranging through measures for contending with it. In addition, it would be useful, in addition to the agrometeorological reasons for the appearance of droughts and drying winds, to mention the synoptic processes involved in their origin and also more clearly characterize the new soil-protecting agricultural system, successfully employed in contending with unfavorable phenomena in the Kazakhstan and Western Siberia regions.

The sixth chapter is devoted to agrometeorological forecasts and information. The types of agrometeorological servicing of agriculture are described briefly, and great attention is devoted to methods for the compilation of agrometeorological forecasts (heat supply, moisture supply, wintering, yield, etc.). And this has been justified by the practical value which the forecasts have. The chapter gives graphs and prognostic formulas. The importance and effectiveness of forecasts and information releases are demonstrated. The chapter is written concisely, but gives a full idea concerning the present status of the problem.

The agroclimatic resources of the USSR and the world (seventh chapter) is an independent course in itself. The author has here done fairly well with the task of defining the fundamental aspects of the subject. Among them is the concept "climatic and agroclimatic resources." The chapter gives a geography of radiation and thermal resources of the USSR. The agroclimatic conditions of wintering are evaluated. The principles of general and special agroclimatic regionalization of the USSR are presented with examples. Such sections as microclimate and soil climate and regionalization of the USSR on the basis of soil climate were written on the basis of investigations by A. M. Shul'gin. They were logically incorporated into a description of the agroclimatic resources of the USSR. This same chapter has the sections: climate and domestic animals; climate, disease and predators on agricultural crops.

The text ends with an eighth chapter on melioration of the climate of agricultural fields. As indicated at the beginning of the chapter, Soviet science has the task of formulation of the problem of melioration of the climate of agricultural fields and the development of its theory. Professor A. M. Shul'gin has made a considerable contribution to investigation of these problems. Due to his studies it became logical to end the evaluation of agroclimatic resources with the problems involved in improving (meliorating) these resources. First of all, this includes a complex of measures directed to a lessening or elimination of unfavorable climatic phenomena (drought, drying winds, severe cold, frosts, etc.). The theory of melioration of climate is also given in a broader plan. The author enumerates and discusses the basic methods for regulating soil climate and microclimate: water melioration, afforestation for the protection of fields, snow melioration, land melioration, artificial heating, protected soil, meliorative agroengineering measures, etc. The chapter concludes with the regionalization and effectiveness of climatic melioration.

A. M. Shul'gin has written a new, original textbook, written in good language, characterized by a sequential exposition of the material on a rigorous scientific basis. The reviewed textbook, with respect to coverage of the touched-on problems, characterizing the present status of agrometeorology and agroclimatology, its structuring, clarity in formulations and demonstration of the principal points, in the next edition, which in our opinion should be published, can be fully presented as a textbook.

I would like to mention the good printing job done on the book. The figures and maps published in the monograph are very clearly done. It is clear that the academic literature released by the Hydrometeorological Publishing House during recent years is approaching the best examples of printed publications.

The appearance of this new book by A. M. Shul'gin has been received with great interest. Without question, it will be regarded highly by student users, professional agrometeorologists and geographers, and by workers in agricultural production.

MONSOON DYNAMICS. CONTRIBUTIONS TO CURRENT RESEARCH IN GEOPHYSICS. EDITED BY T. N. KRISHNAMURTI, BIRKHAUSER VERLAG, BASEL AND STUTTGART, 1978

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 120-121

[Review by Candidate of Physical and Mathematical Sciences S. O. Krichak]

[Text] The importance of investigations associated with monsoonal circulation of atmospheric processes is obvious. The enormous scale of the phenomenon makes it a significant element in general circulation of the atmosphere. There is no doubt but there is a relationship between monsoon intensity and middle-latitude processes. Interhemisphere interactions also exert a significant influence on the development of monsoon circulation. A mechanism of an inverse influence of monsoonal processes on surrounding regions is not entirely understood but is by no means excluded.

The economic reasons for interest in the investigation of monsoons are also understandable: monsoonal precipitation, for example, actually determines the magnitude of yields in a number of densely populated countries in southeast Asia.

During the last five years two major scientific research experiments have been carried out: "Monsoon-73" and "Monsoon-77." During 1978-1979, within the framework of the FGE, the regional experiment MONEX will be carried out. The USSR is definitely participating in all these observation programs.

Abroad a major contribution to the development of investigations of atmospheric processes during the monsoon period has been made by a team headed by a professor at the University of Florida, Doctor T. N. Krishnamurti. Article 21 in the reviewed collection of articles generalizes the results of research which has exerted an appreciable influence on the forming of a number of theoretical concepts and hypotheses concerning the nature of monsoonal circulation, which were adopted by this group. The assertion that the papers presented in the collection define the status of the problem to mid-1976, as stated in the foreword by the editor, is to a high degree correct.

The range of discussed problems is extremely broad. Virtually all of the presented investigations are characterized by interest in ascertaining the physical factors and the phenomena observed in nature. The matter of investigation of the vorticity balance was dealt with in a study by J. S. Fein, and especially C. P. Chang. A matter of particular interest, discussed here, is the problem of the possible mechanism of dissipation of vorticity. The Chang paper also examines the problem of the physical interpretation of the results of spectral analysis of meteorological elements, dealt with in greater detail in an article by M. Murakami.

The problems involved in atmospheric energy were examined in articles by T. Murakami -- regional aspects -- and A. H. Oort and P. H. Chan. The latter investigation seems particularly important. Here, on the basis of material from five-year archives 1958-1963 and 1968-1973 a study was made of the role of the Asiatic monsoon in maintaining the balance of the moment of momentum and kinetic energy of mean flow in the tropics. It was demonstrated that almost the entire transport of the mentioned characteristics from the tropics into the middle latitudes in winter is accomplished through the northern boundary of the monsoon region. In summer in the monsoon region there is a loss of the moment of momentum. As a result, there is a decrease (and toward the middle of summer -- a change in sign) of transport into the middle latitudes.

The papers by T. N. Krishnamurti, et al., A. Gilchrist and W. M. Washington, et al., were devoted to an analysis of the influence of simplifications adopted in hydrodynamic schemes used in the modeling of monsoonal processes. The article by Krishnamurti, et al. gives an analysis of the results of numerical forecasts in the investigated region. Gilchrist carried out a study of the results of modeling of the elements of monsoonal circulation in four present-day models of general circulation of the atmosphere. The article by Washington was devoted to an exposition of the results of experiments for study of the role of the water temperature anomaly in the Indian Ocean in modeling general circulation of the atmosphere. The problem of hydrodynamic modeling of the Asiatic summer monsoon was also covered in an article by D. A. Abbott.

The collection of articles contains many papers devoted to investigation of the elements of monsoonal circulation. Also considered are the problems involved in numerical forecasting of quasistationary long waves (M. Kanamitsu) and a description of the East African low-level jet stream (J. Findlater; J. E. Hart). There is a discussion of the barotropic-baroclinic instability of the mean zonal wind during the period of the summer monsoon (J. Shukla), the evolution and phase changes of a monsoon (P. J. Webster, et al.), a description of processes in monsoonal depressions (R. V. Godbole)(F. H. Sikka), and middle tropospheric cyclones in the summer monsoon (F. H. Carr).

An interesting article by S. Gadgil gives a review of the results of investigations of the influence of orography on the southwesterly monsoon.

We should specially mention a paper by J. S. Winston and A. F. Krueger. It gives an analysis of the radiation characteristics measured by meteorological satellites. The articles of R. Ananthakrishnan and B. K. Cheng are devoted to a synoptic-statistical description of the studied phenomenon.

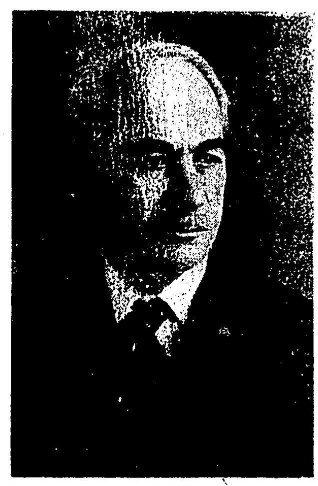
Due to the great number of investigations diverse in subject matter and research methods employed we will not dwell on a discussion of details and comments of a particular nature. We note, however, that the high level of research conducted and the breadth of the problem make the reviewed publication an important stage in the study of monsoonal circulation.

BIRTHDAY OF GRIGORIY NIKOLAYEVICH KHMALADZE (ON HIS 75th BIRTHDAY)

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 122-123

[Article by G. G. Svanidze and V. Sh. Tsomaya]

[Text] Grigoriy Nikolayevich Khmaladze began his work activity in his student days as a common worker. In 1930 he worked at the Transcaucasus Hydrometeorological Commission as a second-class scientific specialist. During the years which followed he was an engineer, senior engineer, head of the Water Inventory Bureau, and head of the Section on Study of the Hydraulic Regime. G. N. Khmaladze always ably combined practical activity with scientific research in the field of hydrometry.



After defense of his Candidate's dissertation in 1951 Grigoriy Nikolayevich was invited to work, in addition to his other work, at the Georgian Institute of Hydraulic Engineering and Melioration in the post of senior scientific specialist, and then as deputy head of the Section on Mining Melioration, where he made mudflow investigations.

We should mention a number of his works which have practical application. For example, GIDROMETRIYA I GIDROLOGIYA R. IORI (Hydrometry and Hydrology of the Iori River) (1947) served as a basis for planning the Samgorskoye Reservoir; GIDROLOGICHESKIYE RASCHETY PO MALYM REKAM (Hydrological Computations for Small Rivers), ISPARENIYE S POVERKHNOSTI SUSHI PO TERRITORII GRUZINSKOY SSR (Evaporation from the Land Surface Over the Territory of the Georgian SSR), VODNYYE RESURSY REK KURA I ARAKS (Water Resources of the Kura and Araks Rivers) constituted the basis of a general scheme for the use and preservation of water resources, etc.; a number of studies were devoted to an investigation of the nature, conditions of formation and classification of mudflows over the territory of Georgia and Armenia.

During the period 1942-1952, at the Administration of the Hydrometeorological Service of the Georgian SSR, G. N. Khmaladze was the director of hydrographic reconnaissance work and the author of a number of descriptions of rivers and also the compiler and editor of hydrological yearbooks for 1938-1951.

Beginning in 1953 G. N. Khmaladze worked at the Transcaucasian Scientific Research Hydrometeorological Institute as chief of the section on hydrological research and forecasts, and beginning in 1978, as a senior scientific specialist in this same section. G. N. Khmaladze has written about 200 scientific studies devoted to the water, thermal and ice regimes of mountain rivers, water resources, water balance investigations and river sediments of the rivers of Transcaucasia. These studies are widely known in the USSR and abroad and are used by planning and engineering agencies.

Devoting particular attention to the development of investigations of the sediments in mountain rivers, in a number of studies G. N. Khmaladze gave a generalization of observational data for the rivers of Transcaucasia, the shores of the Black Sea in the Caucasus area and the southern shores of the Crimea and published them in a series of monographs and articles. One of these monographs served as a basis for his doctoral dissertation, which he defended in 1965. In this monograph, for the first time on the basis of long-term observations, he analyzed a complex of problems, among them the sediments of Armenian rivers, hydrological study of the territory, composition and runoff of suspended sediments and mudflows. He also dealt with the problems involved in the distribution of sediments in the channel cross section, along the length of rivers, over a territory and in time. Much attention was devoted to water turbidity and the runoff of suspended river sediments in dependence on natural factors. For a number of elements he gave practical recommendations on their computation for unstudied rivers. The results of these investigations are used by planning agencies in the Armenian SSR.

Grigoriy Nikolayevich devotes much attention to the education and training of young hydrologists. Over a period of 11 years he did teaching work at Tbilisi State University and trained many graduate students.

G. N. Khmaladze is well known as a leading scientist, unlimited in his dedication to science and loving his work. Unlimited energy, involvement and enthusiasm, in combination with high demands on himself and his students have earned him merited authority and respect among the hydrologists of our country. His scientific and teaching work has repeatedly been recognized by expressions of appreciation. He has been awarded ten government medals and two diplomas by the Presidium of the Supreme Soviet Georgian SSR.

AT THE USSR STATE COMMITTEE ON HYDROMETEOROLOGY AND ENVIRONMENTAL MONITORING

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 p 123

[Article by V. Zakharov]

[Abstract] An expanded session of the Board of the USSR State Committee on Hydrometeorology and Environmental Monitoring was held in Moscow during the period 27-28 March 1979.

The session heard a report by the Chairman of the State Committee on Hydrometeorology and Environmental Monitoring Yu. A. Izrael' entitled "Basic Results of Activity During 1978 and Objectives for 1979 in Light of the Resolutions of the November (1978) Plenary Session of the Central Committee CPSU, Conclusions and Directions Set Forth in the Addresses of the General Secretary Central Committee CPSU, Chairman of the Presidium USSR Supreme Soviet Comrade L. I. Brezhnev."

At the beginning of his report Yu. A. Izrael' stated that by a decree of the Presidium USSR Supreme Soviet dated 30 March 1978 the Main Administration of the Hydrometeorological Service of the USSR Council of Ministers was transformed into the USSR State Committee on Hydrometeorology and Environmental Monitoring and the present session for the first time was being carried out within the framework of this Committee.

Then in the report he dealt with the questions of hydrometeorological support for the national economy, monitoring of environmental contamination, scientific research, expeditionary investigations, international scientific and technical cooperation, technical development, major construction, material-technical support, financial-economic activity, work with personnel, work hygiene and safety.

In conclusion Yu. A. Izrael' discussed the principal problems, including those following from the transformation of the Main Administration of the Hydrometeorological Service into the USSR State Committee on Hydrometeorology and Environmental Monitoring. The speaker emphasized that hydrometeorological support of the national economy remains one of the most important problems. Among the other problems is monitoring environmental contamination, geophysical monitoring and artificial modification of meteorological processes, etc.

Speaking in the discussions of the report were representatives of the Administrations of the Hydrometeorological Service, scientific research institutes, hydrometeorological technical schools, the central offices of the USSR State Committee on Hydrometeorology and Environmental Modeling, the Central Committee of the Trade Union of Aviation Workers, serviced ministries and departments.

Many of those speaking supplemented the speaker, telling about the work plan and socialists obligations for 1978 implemented by the institutes which they represent, about existing difficulties and shortcomings, and about measures taken for their elimination. The representatives of the institutes spoke of the imperfection of the existing system for the planning of scientific research and experimental design work, the necessity for intensifying and improving the organization of research for the development of methods used in weather forecasting, especially long-range forecasts, and increasing the role played by coordinating institutes in the direction of research.

In his concluding words Yu. A. Izrael' answered the questions put to him and gave interpretations of individual communications.

With respect to the considered problem the board adopted an expanded decree. The session participants unanimously approved a letter addressed to the Central Committee CPSU, Presidium of the USSR Supreme Soviet, USSR Council of Ministers and General Secretary Central Committee CPSU, as well as the Chairman of the USSR Supreme Soviet, Comrade L. I. Brezhnev.

CONFERENCES, MEETINGS AND SEMINARS

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 pp 123-128

[Article by N. A. Chernysheva, S. A. Mashkovich, G. K. Zubakin, B. A. Kogan, V. G. Fedorey and V. V. Pokudov]

[Text] An All-Union Conference-Seminar on the Theme: "Problems in Plotting Hydrological Information on Technical Carriers and its Processing Using an Electronic Computer" was held at Obninsk during the period 13-16 March 1979. The conference was attended by specialists of eight computation centers and many hydrometeorological observatories of the Goskomgidromet (USSR State Committee on Hydrometeorology and Environmental Monitoring).

V. A. Semenov, who heads the State Water Inventory Data Center of the VNIIGMI-MTsD (All-Union Scientific Research Center of Hydrometeorological Information-World Data Center), presented a review report on the state of automated processing of hydrological data and creation of data banks for the State Water Inventory and Survey on technical carriers. Representatives from the computation centers informed the audience about the status of punching and processing of hydrological data on a "Minsk-32" computer at the Administrations of the Hydrometeorological Service which they service. In the entire network of posts of the Goskomgidromet there is a changeover to the registry of observational data in record books of a new design adapted for punching the results of measurements directly from them. The punching is accomplished primarily by the specialists at hydrological and mouth stations.

During 1977-1978 programs for the processing and checking of data from observations of water level and temperature, ice thickness and depth of snow on ice, status of water bodies and measurements of water discharges, developed at the VNIIGMI-MTsD, were introduced at the computation centers. Since early 1979 the computation centers of the Goskomgidromet have been making use of 12 kinds of programs for the mathematical support of "Minsk-32" electronic computers which will make it possible to proceed to automated processing, checking and plotting on long-term carriers of all data from hydrological posts on the water and ice-thermal regimes of rivers, the runoff of suspended and entrained alluvium, their granulometric composition.

The specialists at the VNIIGMI-MTsD have also developed programs for producing most of the tables in the annually published materials of the State Water Inventory on a "Minsk-32" electronic computer, including automated computation of daily water discharges for conditions of an unambiguous dependence of water discharges on water levels.

On the basis of the methodological recommendations formulated by specialists of the State Water Inventory Data Center, the VNIIGMI-MTsD and the State Hydrological Institute, since 1978 the hydrologists at hydrometeorological observatories have been carrying out preparations for the registry of data from hydrological observations over a long-term period on a technical carrier.

Specialists of the VNIIGMI-MTsD F. F. Ivanov, G. A. Zaimskikh, G. V. Lesnikov, M. A. Shipulin and L. I. Yakovenko familiarized the seminar participants with algorithms and programs for the automated processing of hydrological data on a "Minsk-32" electronic computer and the collection of annually published materials of the State Water Inventory.

Specialists of the VNIIGMI-MTsD, State Hydrological Institute, and also representatives of the Goskomgidromet T. N. Chizhmakov and Yu. P. Ponomarev, answered numerous questions.

The seminar participants were familiarized as well with methods, algorithms and the status of development of programs for an improved system for the automated processing, storage and dissemination of data of the State Water Inventory on the basis of a Unified Series electronic computer.

N. A. Chernysheva

The Eleventh All-Union Conference on Mathematical Modeling of Circulation of the Ocean and Atmosphere was held during the period 2-12 April in Yalta. These conferences are regularly organized by the Leningrad Division of the Institute of Oceanology USSR Academy of Sciences. A characteristic feature for the conferences is a broad and thorough discussion of this important and complex problem, and also a number of related problems. Conferences evoke great interest in the scientific community: participating in the work of this conference were representatives of 16 scientific institutes and colleges (Institute of Oceanology, Institute of Physics of the Atmosphere, Computation Center Siberian Department USSR Academy of Sciences, Computation Center USSR Academy of Sciences, Marine Hydrophysical Institute, USSR Hydrometeorological Center, Main Geophysical Observatory, Arctic and Antarctic Scientific Research Institute, State Hydrological Institute, Odessa Hydrometeorological Institute and others). During the conference there were also sessions of a seminar on geophysical hydrodynamics. A total of 38 reports and lectures were presented.

A large group of reports were devoted to the climate problem. Here, in particular, we should mention the report of Ye. P. Borisenkov, which described some climatic models and cited evaluations, obtained on their basis, of the sensitivity of climate and its possible changes under the influence of different factors. Particular attention was given to the modeling of the carbon cycle in the "ocean-biosphere" system and its influence on climate.

The second report of Ye. P. Borisenkov was devoted to the modeling of the climatic regime of the atmosphere and the underlying surface of Mars.

A report by D. D. Kvasov, A. P. Gal'tsov and A. S. Safray dealt with the greenhouse effect in the atmospheres of the Earth and Venus. D. V. Chalikov, D. D. Kvasov and M. Ya. Verbitskiy presented a mathematical model of a large ice shield. The modeling of the heat regime of Antarctica, taking into account long-period climatic variations, was discussed by V. R. Barabash. I. L. Karol' devoted his report to the systemic approach and modeling of atmospheric processes and illustrated this approach in the example of chemical processes in the atmosphere and formation of ozone distribution.

The problem of modeling of climate in a system of biospheric models was discussed by V. V. Aleksandrov, who also demonstrated motion picture films taken on the basis of numerical experiments on general circulation of the atmosphere within the limits of a two-level model. In general, considerable attention was devoted to investigations of general circulation of the atmosphere at the conference and a number of reports were presented. V. P. Dymnikov and V. L. Petrov reported on a model of zonal circulation of the atmosphere developed at the Computation Center Siberian Department USSR Academy of Sciences and presented some results of numerical experiments carried out on the basis of this model. In this report great attention was devoted to the problems involved in parameterization of processes on a sub-grid scale in a zonal model and interesting proposals were made relative to closing the system of equations. B. Ye. Shneyerov presented information on a five-level model of general circulation of the atmosphere developed at the Main Geophysical Observatory and about its use for reproducing the mean state of the atmosphere in January. M. B. Galin and S. Ye. Kirichkov reported on investigations of general circulation of the atmosphere on the basis of a model with few (14-component) parameters. The presented results of the computations demonstrated the possibility of a correct description of the important characteristics of general circulation of the atmosphere within the framework of such relatively simple models. A communication by Yu. D. Resnyanskiy was devoted to problems relating to joint circulation of the atmosphere and ocean.

Definite attention was devoted to long waves in the atmosphere: two-dimensional Rossby solitones were examined (V. D. Larichev, G. M. Reznik); a paper dealt with the results of laboratory and theoretical investigation of barotropic Rossby waves in a rotating annular channel (F. V. Dolzhanskiy, M. V. Kurganskiy, Yu. L. Chernous'ko). Autooscillations and irregular regimes in a model with few parameters were the theme of a report by F. V. Dolzhanskiy and L. A. Pleshanova. The report of Ye. A. Novikov was devoted to the stochastic transformation and collapse of eddy systems. The author studied the behavior of a system of four eddies and explained the conditions for the existence of an oscillatory regime and the appearance of a stochastic process, associated with the fusing or breakdown of eddies (collapse). A large group of reports was devoted to problems related to the modeling of circulation in the ocean: an integral model of the main thermocline (P. S. Lineykin), a numerical model of wind waves (D. V. Chalikov, V. K. Makin), a model of wind waves with few parameters (M. M. Zaslavskiy, A. Yu. Benilov), a one-dimensional integral model of the active layer of the ocean (A. I. Fel'zenbaum), a two-dimensional model of evolution of synoptic eddies in the ocean (E. A. Mikhaylov, N. B. Shapiro), a model of mesoscale circulation in the ocean (I. A. Neyekhov, V. D. Chalikov), correctness and approximate solutions of linear problems of dynamics of a baroclinic ocean (M. A. Bubnov), reactions of the ocean to typhoons (G. G. Sutyrin), computation of the characteristics of the quasi-isothermic layer in the equatorial zone of the ocean (A. B. Polonskiy), parameterization of shelf effects in models of oceanic tides (B. A. Kagan, V. Yu. Gotlib), modeling of large-scale currents in the ocean (V. P. Kochergin, V. A. Sukhorukov, V. N. Klimok), numerical experiments on the distribution of tracers in the world ocean (B. A. Kagan, V. A. Ryabchenko), and others.

Several lectures were also presented, among which we can mention lectures devoted to modern changes in climate and the productivity of vegetation (G. V. Menzhulin) and a review of climatic data (K. Ya. Vinnikov).

S. A. Mashkovich

A regional conference on investigation of ice in northwestern seas was held in Murmansk during the period 28 February-2 March. The conference heard and discussed more than 50 reports on the problems relating to investigation of ice and the development of new methods for computing and predicting ice characteristics for supporting navigation, fishing and geological exploration work, as well as the influence of the ice cover on biological processes in the ocean.

The conference was opened by the Chairman of the Murmansk Division of the Northern Affiliate of the USSR Geographical Society, the head of the Murmansk Administration of the Hydrometeorological Service, Ya. P. Popov. In the introductory remarks, a member of the board of the Ice Section of the Oceanographic Commission, USSR Academy of Sciences, V. L. Tsurikov, discussed the results of section work during the period elapsing after the similar conference in Vladivostok (1975).

The reports presented at the conference can be classified into five main groups corresponding to the directions in investigation of sea ice in our country.

1. Experimental investigations. The conferees exhibited particular interest in a report by A. V. Bushuyev, N. A. Volkov and Z. M. Gudkovich (Arctic and Antarctic Scientific Research Institute) on the problems and methods for complex study of the ice cover of the Kara Sea. It presented an expanded

standard program of experimental investigations of the principal laws of thermal and dynamic processes in the ice cover, in the boundary layers of the "ocean-ice-atmosphere" system, morphometric and physical characteristics, processes of contamination of sea ice, propagation of river waters and their influence on the hydrological, hydrochemical and ice regimes.

It is proposed that use be made of the scientific research icebreaker "Otto Shmidt" as the main base for comprehensive investigations of northwestern seas. Z. N. Gudkovich familiarized the conferees with experience in carrying out such experiments in the Laptev Sea and the results of studies. The results of five years of investigations of the dynamics of the ice cover in the Barents Sea were covered in a series of reports presented by the Murmansk Affiliate of the Arctic and Antarctic Scientific Research Institute.

An important direction in study of the state of the ice cover and its rheological properties was covered in the reports of V. V. Bogorodskiy, V. P. Gavrilo, K. K. Sukhorukova and V. A. Nikitin (Arctic and Antarctic Scientific Research Institute).

Investigations and field measurements of nonuniformities in the thickness of the ice cover of Arctic seas enabled A. A. Kirillov and V. A. Spichkin (Arctic and Antarctic Scientific Research Institute) to propose a method for organizing observations of the thickness of sea ice at polar stations, which caused lively interest.

2. Mathematical modeling and theoretical investigations of the ice cover under the influence of perturbing forces.

A general evaluation of employed Lagrangian models of behavior of sea ice under the influence of dynamic and thermal factors and the prospects for the development of this direction were given in a report by S. N. Ovsiyenko and V. O. Efroimson (USSR Hydrometeorological Center). The investigations of D. Ye. Kheysin and M. I. Maslovskiy (Arctic and Antarctic Scientific Research Institute) revealed earlier unknown inertial oscillations of the velocity vector of ice drift. The model computations presented by the authors convincingly demonstrate the presence of the noted phenomenon.

The mathematical modeling of ice redistribution during the summer period was the subject of a report by I. L. Appel' and Z. M. Gudkovich (Arctic and Antarctic Scientific Research Institute). The model uses a combination of hydrodynamic and statistical methods making possible its use for long-range forecasting. Some problems in the theory of nonstationary drift of sea ice were solved in a report by G. K. Zubakin and V. R. Potapov (Murmansk Affiliate Arctic and Antarctic Scientific Research Institute). A communication by V. Ye. Lagun and V. F. Romanov (Leningrad State University, Arctic and Antarctic Scientific Research Institute) proposed a parametric system describing the boundary layers of the ocean and the atmosphere interacting with the ice. There was a discussion of the possibilities of using the system in models of global circulation of the atmosphere and ocean and in problems of dynamics of the ice cover. The results of theoretical investigations of oscillations of the ice cover in the presence of perturbing forces of different nature were reported by representatives of the Marine Hydrophysical Institute Ukrainian Academy of Sciences (A. M. Suvorov, L. V. Cherkesov and A. Ye. Bukatov).

3. The use of numerical methods for computations and predictions of state of the ice cover.

The putting of mathematical models of the redistribution of ice cover in seas into practical use in prediction and computation schemes is a very important and complex problem. Its importance is obvious since existing physical-statistical methods do not always afford a possibility for predicting many elements of state of the ice cover under the influence of dynamic and thermal factors. It is a complex problem due to the frequent absence of initial parameters, reliable meteorological forecasting, high-speed electronic computers capable of ensuring routine work, etc.

Despite the difficulties, during recent years such methods have been gradually introduced into the practice of servicing of Arctic navigation. In a report on this problem I. L. Appel', Z. M. Gudkovich and V. P. Karklin (Arctic and Antarctic Scientific Research Institute) examined a scheme for predicting the distribution of ice in the southwestern part of the Kara Sea for a week in advance, which was used during 1977-1978 for operations in the Kara Sea.

A method for the short-range forecasting of ice compression in the southwestern part of the Kara Sea for ensuring navigation operations in the Kara Sea was presented in a report by a group headed by L. A. Timokhov (Arctic and Antarctic Scientific Research Institute).

A numerical model and scheme for prediction of the compression and thinning of the ice cover, the position of the ice edge and boundaries of ice of different continuity for the Barents Sea (G. K. Zubakin, L. N. Zuyev, Murmansk Affiliate Arctic and Antarctic Scientific Research Institute) were used in construction of a prognostic ice map using an electronic computer. All the enumerated forecasting elements were fed out in mapped form using a drafting machine. Then, using a facsimile machine, the prognostic map is transmitted to interested organizations. According to the results of 1978, the probable success of the forecasts averages 80%.

It should be emphasized that the use of the above forecasting methods was dictated by the practical needs for ensuring year-round navigation in the western sector of the Arctic.

A report by I. Ye. Frolov, T. M. Moskal' and I. F. Romantsov (Arctic and Antarctic Scientific Research Institute), entitled "Mathematical Model of Autumn-Winter Ice Phenomena and the Results of its Testing in the Barents and Kara Seas," was of great interest to professional forecasters. The computations will probably reflect the state of the ice cover in the winter of 1979.

4. The use of physical-statistical methods in investigations and prediction of processes of a large-scale nature.

A. A. Lebedev (Arctic and Antarctic Scientific Research Institute) reported on the correlation between ice processes in the Arctic and Atlantic Oceans. The determined qualitative and quantitative relationships between different hydrometeorological factors and ice enabled the author to clarify some physical mechanisms of the processes of different time scales.

The reports of B. A. Kogan, V. I. Turchaninov and A. A. Kosolapov (Murmansk Affiliate Arctic and Antarctic Scientific Research Institute) were devoted to investigations of the position of the ice edge in the Labrador Sea and the possibility of its long-range forecasting during the winter period. The results obtained and the high probable success of the forecasts (80-90%) make it possible to introduce the proposed methods into practical forecasting work.

O. I. Sheremetevskaya reported on study of the statistical structure of the times of first appearance of ice in the Barents, White and Baltic Seas at the USSR Hydrometeorological Center. The results of the investigation are a prerequisite for background long-range prediction of the phases of autumn ice phenomena in the seas of the European USSR. The reports of V. N. Kupetskiy and V. A. Kalesnik (Arctic and Antarctic Scientific Research Institute, Northwestern Administration of the Hydrometeorological Service) were of definite interest. They were devoted to the use of homologues of solar activity in an investigation of ice processes and climate of the Baltic, Barents, Greenland and Kara Seas. The problems involved in the long-range prediction of ice content of the Barents Sea on the basis of the change in some dynamic characteristics of the sea were examined in a report by V. Sh. Sagdeyev and V. A. Potanin (Murmansk Affiliate Arctic and Antarctic Scientific Research Institute).

5. Practical investigations relating to the state of the ice cover.

Ya. L. Kostykov (Administration of the Hydrometeorological Service of the Latvian SSR) reported on the variability of conditions for navigation in the ice in the Gulf of Riga and the possibilities of predicting extremal conditions. In a report by V. L. Ivanov and V. A. Zalitskiy (Sevmorgeo Trust), entitled "Hydrometeorological Servicing of Reconnaissance Work Abroad," desires and comments were expressed concerning similar servicing in our country.

The role of ice conditions in the formation of populations of the ringed seal in the White Sea and in the southeastern part of the Bering Sea was noted in a report by L. R. Lukin (Northern Administration of the Hydrometeorological Service). The conferees devoted much attention to a report by I. A. Mel'nikov (Institute of Oceanology) concerning experimental investigations of ecosystems on the "SP" drifting stations.

At the conference reports were also presented by K. G. Konstantinov and V. P. Sorokin (Polar Scientific Research Institute of Fishing and Oceanography), V. L. Tsurikov (State Oceanographic Institute), A. V. Bushuyev and Yu. D. Bychenkov (Arctic and Antarctic Scientific Research Institute), Ya. P. Popov and B. D. Popov (Murmansk Administration of the Hydrometeorological Service) and others.

G. K. Zubakin and B. A. Kogan

The Fourth Symposium on Joint Study of the Kuroshio (JSK) was held in Tokio during the period 14-17 February. JSK programs carried out since 1965 were summarized.

The symposium was attended by about 80 scientists from Australia, Chinese People's Republic, Fiji, India, Indonesia, Korea, Malaysia, New Zealand, New Guinea, New Caledonia, Philippines, Thailand, Hong Kong, USSR, United States and Japan. More than 70 reports were presented. The USSR delegation (delegation headed by V. G. Fedorey) was represented by 10 reports, of which eight were presented during the work of the symposium.

The symposium was opened by Prof. A. I. Takenouti, who greeted the participants and wished them success in their work.

After opening of the symposium three leading scientists from Japan, USSR and the Philippines presented generalizing lectures before all the symposium participants: Professor Ken Sugawara presented a review of activity of the JSK in the field of investigations of sea contamination, Professor O. I. Mamayev reported on the structure of waters in the Sea of Japan, and Doctor Inocenzio Ronquillo presented a review of attainments of the JSK in the field of investigations of the state of fish reserves.

All the remaining work of the symposium was carried out in sections in which all the reports on the same subjects were combined and discussed. Eight sections operated.

1. Dynamics of the Kuroshio -- 13 reports;
2. Descriptive and fishing oceanography -- 11;
3. Marine geochemistry -- 5;
4. Environmental quality -- IO;
5. Biology and biochemistry -- 11;
6. Biological productivity and living resources -- 13;
7. Interaction between the ocean and the atmosphere -- 5;
8. Marine geology -- 7.

In all the presented reports the variability of phenomena and processes was examined on broad time and space scales. In some studies there was an investigation of the entire Pacific Ocean, whereas in others -- only the coastal regions. The time scale took in periods from 100 days to several days.

Five reports were devoted to large water circulations and eddies. There was a discussion of the anomalous development of one of the quasi-stationary cyclonic curvatures of the Kuroshio to the south of Honshu.

The reports presented on the subject of marine geochemistry demonstrated the recent attainments in this field. There was a discussion of problems relating to heavy metals, organic carbon and its varieties, and also chlorinated hydrocarbonates and petroleum.

Biological problems were reflected in 24 reports of the fifth and sixth sections. Investigations of benthos, corals, zoo- and phytoplankton of the waters of the Kuroshio and adjacent regions were presented.

Materials revealing the reasons for the rapid increase in the population of Japanese sardine since 1970 were important from the practical point of view.

Reports pertaining to living species of fish and the fish industry as a whole were also interesting. Scientists have concluded that the data collected at the present time do not explain the annual fluctuations either in the environment or in the supplies of fish, but such investigations must be encouraged for the purpose of a better understanding of the "status of the modern fishing industry."

In the section "Interaction Between the Ocean and the Atmosphere" a study was made of a number of problems having prognostic importance: the influence of the Kuroshio on local characteristics of precipitation in the Philippines, the possible dependence of meandering of the Kuroshio on solar activity, the influence of typhoons on the Kuroshio and the relationship between the intensity of the Kuroshio and wind fields over the ocean near the Hawaiian Islands.

In the implementation of the JSK program considerable progress has been attained in the understanding of the marine geology and geophysics of the western part of the Pacific Ocean. The presented reports examined the results of recent years, mentioned unsolved problems and gave practical recommendations on the future.

In general, I would like to note that in connection with the proposed discussions of the "WESTPAC" program, at the fourth symposium great attention was devoted to recommendations on scientific research for the future. The scientists of the countries participating in the JSK program unanimously came to the conclusion that during the 13 years of existence of the program much material had been accumulated and they are leading to a better understanding of many aspects of the Kuroshio and the Pacific Ocean as a whole, but the breadth and complexity of the ocean are so great that our "knowledge of it is nevertheless very limited. Therefore, in the future there must be more concentrated actions by an exchange of ideas, methods, data and other necessary information among the countries of this region" (from a summary of symposium materials).

NOTES FROM ABROAD

Moscow METEOROLOGIYA I GIDROLOGIYA in Russian No 7, Jul 79 p 128

[Article by V. I. Silkin]

[Text] As reported in NATURE, Vol 274, No 5671, p 580, 1978, in the implementation of the program for the International Decade for Study of the Ocean scientists of the United States and Japan carried out a joint analysis of the totality of data describing the Kuroshio Current. Among these data are the communications of the Japanese Agency for the Safety of Navigation, covering two-week time intervals, regular results of measurements of current velocity and water temperature in it, carried out by weather ships at depths of 0, 100 and 200 m, and other materials of the Japanese Meteorological Agency and the Hydrographic Administration.

As early as 1870 it was noted that the Kuroshio, usually flowing parallel to the eastern shore of Honshu Island, sometimes in the region of Cape Misaki forms a major meander (curvature) reaching as far as 30°N. Now this has been confirmed by observations carried out at a modern scientific level. It is particularly easy to trace the processes of formation of three meanders arising under definite conditions during the period between 1934 and 1963.

The easily traced process of formation of a meander in 1977 had interesting peculiarities. Even in the second half of February it was situated in the usual region for the appearance of meanders, to the west of the underwater Idzu-Ogasawara Ridge. However, in mid-May the curved flow began to be drawn out in the direction SSE of Cape Misaki. At the end of the month an annular current or ring was separated from it and subsequently existed independently.

The Kuroshio meander corresponding to this ring began to contract and by July merged with the main channel of this current. A month later the ring also virtually ceased to exist, rejoining the main flow of the Kuroshio. The only remaining trace of its existence was a large meander situated to the west of the site of initial ring generation.

Comparison with similar processes observed earlier in the Gulf Stream revealed the following difference. The rings arising in the Atlantic Ocean had a tendency then to move in an eastward direction, whereas the Kuroshio rings were characterized by movement to the west. The hydrologists concerned with theory must propose a sound explanation for such a difference.

[10-5303]

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